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Evaluation of a flushing-gutter manure-removal system to improve atmospheric quality in housing for laying hens

Robert Lee Fehr
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Evaluation of a flushing-gutter manure-removal system to
improve atmospheric quality in housing for laying hens

by

Robert Lee Fehr

A Dissertation Submitted to the
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INTRODUCTION

The United States is engaged in the world-wide effort of providing food to an ever-increasing population. Supplies of land capable of crop production are finite and in some areas, such as the United States, there is little remaining land capable of profitable crop production which is not in use. Therefore, in order to feed an increasing population on a finite land area, one goal must be to increase the production capability of crops and livestock. Another goal must be to increase the efficiency with which these food sources are used.

In order to meet the present consumer demand for varied types of foods, a major portion of our crop production is fed to animals. Should these preferences for animal products continue, then the animal producer will be encouraged even more to use the most efficient method of production which is economically feasible especially if the feed is derived from crops suitable for human food. To aid the animal producers, research is needed to determine that environment which promotes maximum production and then to develop methods whereby this environment can be economically obtained in large-scale production facilities.

Egg production, like the majority of animal-production industries, has been influenced by the economic conditions of past years to become consolidated into fewer but larger production units. In Iowa, the number of farms reporting hens and pullets of laying age decreased from 23,269 in 1970 to 15,236 in 1972. Of the 15,236 poultry farms in Iowa in 1972, the majority of birds, 70%, were on 3% of the farms

(Iowa Crop and Livestock Reporting Service, 1974).

While egg production increased in the entire United States from 58,954 million eggs in 1950 to 70,110 million eggs in 1970, egg production in Iowa declined during the same 20-year period from 4,652 to 3,034 million eggs (U.S.D.A., 1971). By 1973, Iowa production had continued downward to slightly over 2,000 million eggs, with cash receipts of approximately 76 million dollars (U.S.D.A., 1974). Thus this reduction in egg production in Iowa also results in reduced gross cash flow of agricultural production in the state.

The reduction in egg production in Iowa has been the result of several factors of which one is climate. The temperature inside a poultry-production unit can be more easily controlled within the most productive range of 7° to 24°C , if the outside temperatures do not differ greatly from the productive range. In Iowa, however, the normal winter temperature goes below -21°C approximately 54 hours each winter; in the summer, temperatures above 33°C occur approximately 75 hours. Because of these differences between the normal outside temperature range in Iowa and the most productive range for egg production, buildings must be well insulated for the winter conditions and well ventilated for summer conditions. By contrast, the two leading egg-producing states, California and Georgia, have climates which range from 0°C in winter to 35°C in summer, which allow producers to use lesser insulated and less expensive buildings than producers in Iowa. This relative advantage in climate is partly responsible for the shift in major egg-producing areas over the past 20 years from the Midwest to California and the southeastern United States.

To maintain egg production in Iowa, methods by which eggs can be produced more economically must be found and these methods should be applicable to both large and small operations to support a wide base of egg production in the state.

PROBLEM

If egg production is to be encouraged in Iowa, it will require methods that make it more economically competitive with other areas of the country. These methods will include cost reductions for construction and maintenance of an egg-production unit that simultaneously provides an equally or more productive environment for egg production. These tend to be conflicting requirements when applied to variable size production units.

Reductions in construction costs can be achieved, on a per-bird-space basis, if the bird density is increased in a production unit. Adams and Jackson (1970) reported that egg production is significantly affected by cage size and bird density. Birds housed in small cages (30.5 x 45.7 cm) produced 4.6 to 7.8% more eggs on a hen-housed basis than those in a comparable house having larger cages (71.1 x 81.3 cm), however, birds housed at low densities (700 cm²/bird) laid 7.9 to 12.4% more eggs than those at high densities (350 cm²/bird). Wilson et al. (1967) observed a similar decrease in per-bird egg production by increasing bird density.

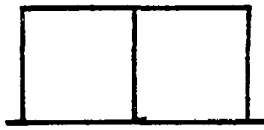
While egg production per bird decreases by increasing the bird density, it is not necessarily unprofitable to increase bird density. Income per unit of cage space can be maximized by caging birds in multiple-cage units (Champion and Zindel, 1968). However, increasing bird density too highly can reduce income per cage. Research indicates that placing a fourth bird in a 30.5 x 45.7 cm cage will reduce net income below that obtained with three birds per cage (Bell, 1972; North, 1974). Annual production per bird will be reduced when the

per bird floor space is less than under 387 cm^2 . Any reduction is significant since a bird may produce only 15 eggs per year more than the number of eggs required to meet her production costs.

Increasing bird density can also be achieved by increasing the number of cages in the building but cage arrangement (Figure 1) is restricted by manure-handling methods (North, 1972). The cage arrangement must allow manure removal from the building without large investments of capital in mechanical devices or large labor requirements. At present, this requires that the manure be allowed to move to the floor where it can be transported out of the building.

Ammonia-gas concentrations below $7 \text{ } \mu\text{g}/\ell$ must be maintained if maximum egg production is expected. With most of the current poultry manure-handling systems, producers have difficulty maintaining low ammonia-gas concentrations in the atmosphere during periods of minimum ventilation. The minimum ventilation rate for poultry housing that is generally recommended as necessary to maintain a low ammonia-gas concentration is $0.014 \text{ m}^3/\text{min-bird}$; however, this rate increases the difficulty of providing a productive temperature environment in the winter because the birds may not produce enough heat to maintain the building temperature in the most productive range. Supplemental heat must then be provided if the most productive temperature is to be maintained which increases both fixed and operating production costs.

To increase production by increasing the number of cages in a poultry building, therefore, will require the development of new manure-handling systems; systems which operate compatibly within the mentioned



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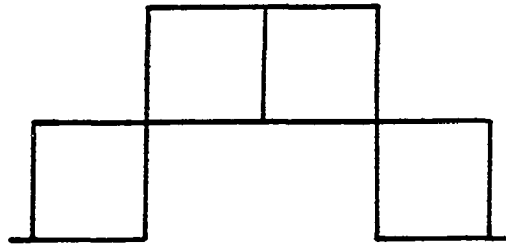
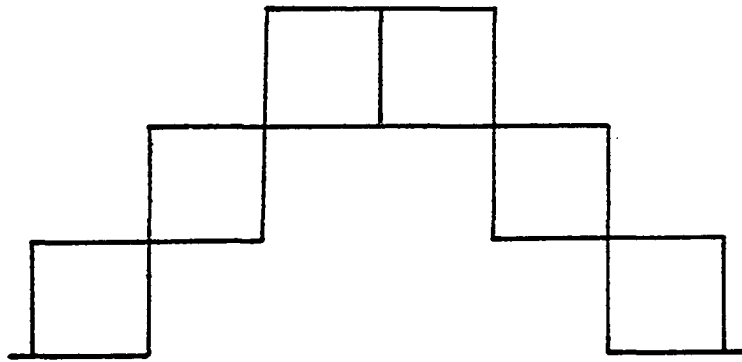
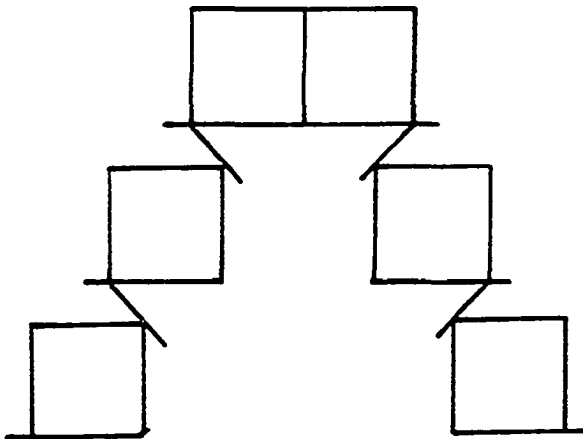
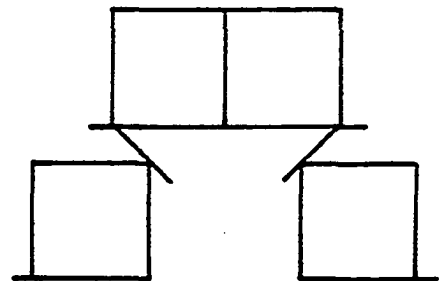
DOUBLE DECK
STAIR STEPTRIPLE DECK
STAIR STEPTRIPLE DECK
OFFSETDOUBLE DECK
OFFSET

Figure 1. Common cage arrangements in laying hen houses (North, 1972)

restraints of economics and a maintained environment for maximum productivity. The development of such systems would appear to be one of the more immediately promising and effective contributions toward preserving the competitive status of egg production in Iowa.

OBJECTIVE

The flushing-gutter, manure-handling system installed at the Poultry Research Center at Iowa State University presents a possible solution to manure-handling problems that currently prevent increased bird density in Iowa poultry buildings. As indicated in the statement of the problem this system must provide a productive environment and be economically feasible to provide a useful method for preserving the competitive status of egg production in Iowa.

Therefore, the primary objective of this research was to test the hypothesis that a flushing-gutter, manure-handling system is capable of providing a productive environment for poultry without a large investment of capital or large labor requirement. To meet this primary objective this research will:

1. Evaluate the effect of a flushing-gutter, manure-handling system on the internal environment of a layer house.
2. Determine the interrelationship between flush-water quality and atmospheric-ammonia concentrations.
3. Measure changes in flush-water quality with time as the flush water is recycled within the building.
4. Compare flush-water quality changes with time under two systems of waterer management.
5. Determine the theoretical economic feasibility of this system.

REVIEW OF LITERATURE

Productive Environments for Poultry

Temperature and humidity

Most research involved in determining a productive environment for egg production is concerned with the air temperature surrounding the hen. Results of research on the effects of air temperature on egg production are typified by Figure 2 (Bond and Kelly, 1960). This shows that with normal housing, egg production is reduced when the air temperature exceeds 21°C or falls below 10°C , with the most dramatic effect on egg production resulting from high temperatures.

As the air temperature rises, many other changes in bird response accompany decreased egg production. Such changes may include increases in water consumption, respiration rate, and body temperature as well as decreases in pulse rate, feed intake, body weight, egg weight, and eggshell quality. However, recent research indicates that some of these effects can interact and result in an economic advantage for higher temperatures. In the early 1960's, researchers noted an increase in feed efficiency with increasing air temperatures (Squibb et al., 1959; Mueller, 1961). Early testing, on the effects of high air temperatures on the feed efficiency of hens, showed significant increases in feed efficiency for hens housed at 32°C when compared to those housed at 13°C (Mueller, 1961). These results were confirmed by Wilson et al. (1972) in recent experiments where hens were housed at 10°C , 24°C , and 36°C .

However, high air temperatures can be detrimental to poultry

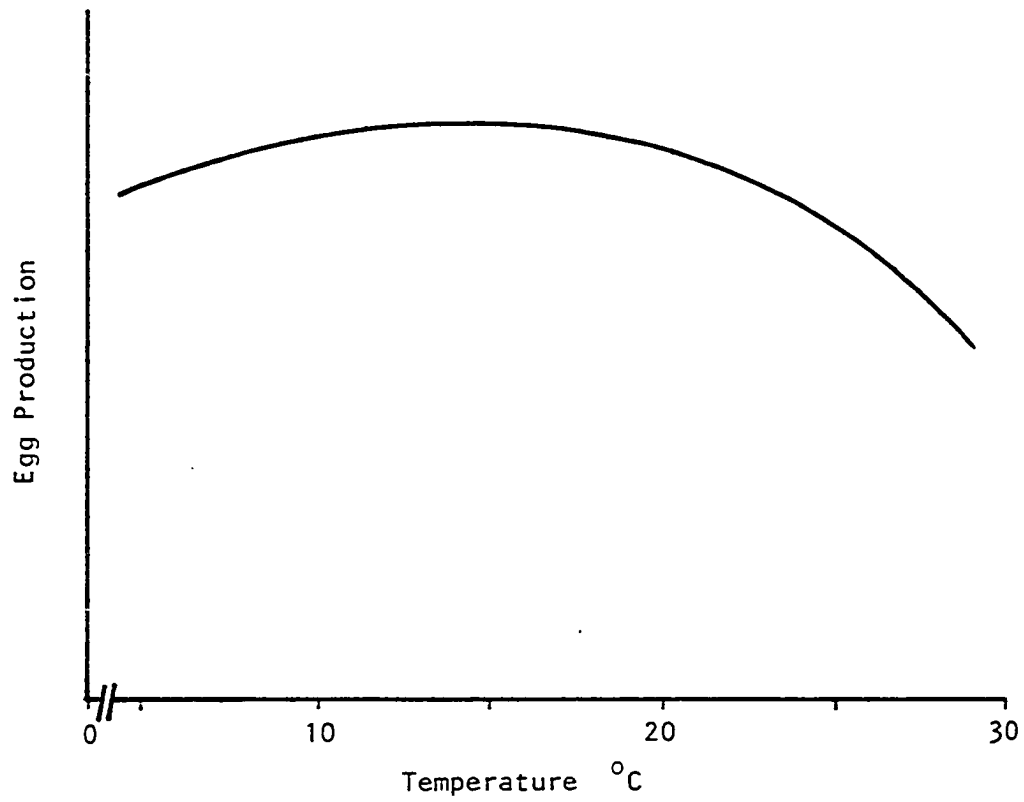


Figure 2. The influence of environmental temperature on egg production trends of laying hens (Bond and Kelly, 1960)

performance because poultry are homeothermic and control their body temperature by adjustments in their heat production and heat loss. Since poultry do not sweat, they use their own respiratory system to aid in cooling (Esmay, 1969). Respiratory cooling involves the release of water vapor while exhaling and may be hampered by water vapor present in high humidity air at high ambient temperatures. Barott and Pringle (1941) conducted research to determine the interaction of high temperatures and humidity on laying hens. Their results, indicated that there was critical humidity for a given temperature above which layers suffered heat prostration and some died. The critical temperature and humidity combinations determined were 32°C-75%, 35°C-60%, 38°C-30%. Reece et al. (1972) studied the combination of high temperature and humidity on broilers and found that at a temperature of 41°C the critical humidity was between 15 and 25% RH. During the testing, Reece et al. also noted that the effects of heat prostration could be reduced if the birds were acclimated to cyclic temperatures.

The beneficial effects of cyclic temperatures on layer performance and physical well-being were noted in the early 1950's (Promersberger and Bryant, 1952). Early researchers noted that average daily temperatures did not account for fluctuations in egg production, while the range of daily temperatures had a significant effect on egg production. Squibb et al. (1959) investigated the effect of wide diurnal temperature fluctuation on egg production by exposing hens to temperatures exceeding 38°C during the day with an average diurnal range of over 28°C. When compared with hens which were never exposed

to temperatures exceeding 27°C and an average diurnal range of less than 11°C, there were no significant differences in egg production or egg weight.

Mueller (1961) also studied the effects of fluctuating daily temperatures by controlling the environment of three groups of hens at a constant 13°C, a constant 32°C, and a daily temperature cycle of 13°- 32°C. The group of hens housed with a cyclic temperature had the highest rate of egg production and the best feed efficiency. Mueller also noted that the hens housed at 32°C had the highest mortality rate which would be a drawback to housing hens at a high temperature to improve feed efficiency. Similar results obtained by Wilson et al. (1972) support the hypothesis that wide diurnal temperature variations are beneficial to the physical well-being and production of laying hens.

Atmospheric ammonia

Temperature and humidity are not the only factors determining a productive environment for egg production; ammonia gas concentrations in the atmosphere have been found to be related to layer well-being and egg production. Reports of outbreaks of severe keratoconjunctivitis were becoming more frequent in the late 1940's. When field analyses were begun to determine the cause (Bullis et al. 1950), it was found that high ammonia concentrations in the atmosphere were common to nearly all cases. Attempts to transmit the disease by direct contact (cotton swabs) and by housing affected birds with healthy birds failed to produce the disease. It appeared from the evidence that ammonia concentrations in the atmosphere played a definite role in the etiology

of the disease.

With the outbreaks of an ocular disorder in Canada, similar to that described by Bullis et al., research was conducted to determine the cause (Wright and Frank, 1957). In many of the instances, there had been a strong smell of ammonia in the poultry house. Attempts to reproduce the condition in healthy chicks with material from affected birds were unsuccessful. However, when healthy chicks were exposed to an ammonia enriched atmosphere for a period of 15 days, the condition was reproduced. The ammonia concentration in the atmosphere during the research was not recorded.

At ammonia concentrations above 42-49 $\mu\text{g}/\text{l}$ Valentine (1964) found an increased incidence of keratoconjunctivitis and tracheitis, due to irritation of the mucous membrane. Tracheitis not only predisposes affected birds to respiratory diseases but also to secondary infections.

Anderson et al. (1964) found that exposure of chickens to low concentrations of ammonia (14 $\mu\text{g}/\text{l}$) did not effect their weight gains. However, this level of exposure produced damage to the integrity of the respiratory tract detectable on gross examination after 6 weeks. Exposure of chickens to 14 $\mu\text{g}/\text{l}$ of ammonia for 72 hours significantly increased their infection rate to an aerosol of Newcastle disease virus. An exposure of 48 hours at a concentration of 35 $\mu\text{g}/\text{l}$ of ammonia produced similar results. The toxic effect of ammonia appears to be related to both its concentration and length of exposure.

G. Petkov (1966) studied the effect of increased concentrations of ammonia on laying hens. He increased the ammonia levels in the

atmosphere to above 348 $\mu\text{g}/\text{l}$ and housed birds for 2 months in the ammonia enriched atmosphere. The results of his tests indicated that egg production is decreased, 9% in his test, with an increase in atmospheric ammonia levels. Ammonia levels of above 348 $\mu\text{g}/\text{l}$ are not representative of conditions which are normal in poultry houses, but these data help to verify the tendency toward decreased egg production with increased ammonia levels.

An extensive research project was conducted in England to determine the effects of lower levels of ammonia on layers (Charles and Payne, 1966). Two groups of layers were housed at 18°C with one group exposed to 36 $\mu\text{g}/\text{l}$ of ammonia while the other group was exposed 73 $\mu\text{g}/\text{l}$ of ammonia. The group of layers housed in 36 $\mu\text{g}/\text{l}$ of ammonia showed no effect while those housed in 73 $\mu\text{g}/\text{l}$ of ammonia had a reduced level of egg production after 10 weeks, reduced feed intake and their live-weight gain was lower. Two other groups of layers were housed at 28°C with one group at 35 $\mu\text{g}/\text{l}$ of ammonia and the other at 71 $\mu\text{g}/\text{l}$ of ammonia. Similar results were obtained as from the tests conducted at 18°C but it was found that the reduced level of egg production could be returned to normal with the use of a high nutrient level ration. Charles and Payne indicated that their most important finding was the reduction of feed intake with increases in ammonia concentrations in the atmosphere.

Other factors

Temperature, humidity, and ammonia concentrations in the atmosphere are the components of the physical environment that

have received the most study in past years. However, other environmental factors may interact with the aforementioned components to produce an unsatisfactory environment for egg production.

One factor which is presently under study is the combination of dust particles and aerosols. It has been postulated that some poultry diseases are transmitted by air currents moving dust particles and aerosols around the bird (Prince et al., 1965).

It is difficult to measure dust particles and aerosols individually; therefore, results of studies on air-borne particulate levels indicate the sum of dust particles and aerosols. In research conducted on air-borne particulate levels, it has been found that bird activity is directly related to the particulate level (Burnett, 1969b; Grub et al., 1965). Factors which increase bird activity will also increase the air-borne particulate level. These factors include birds being removed from their cage, temperatures between 15-21°C, and periods of illumination.

Air-borne particulates in poultry houses are composed of skin debris, feather debris, feed particles, litter, fecal matter, and dust brought into the poultry house by the ventilation system (Grub et al., 1965; Koon et al., 1963). Since litter is a component of air-borne particulates, poultry housing systems that do not use litter, e.g. caged layers, should have lower levels of particulates. Research has shown that there are 4-12 times less particulates in a cage-layer house than a house in which the layers are kept on litter (Grub et al., 1965). In-house manure drying systems will also increase particulate levels if the moisture

content of the manure falls below 25% (Kling and Bressler, 1974).

Particulate matter has been found to be associated with odors coming from the poultry houses (Burnett, 1969b; Eby and Willson, 1969). An odor panel judged that a filter containing particulate matter trapped in a poultry house carried a "chicken house" odor. After 12 hours of exposure to clean air, the filters lost their characteristic odor, which indicates that odors associated with particles are composed of volatile compounds.

Little is known about the effects of some gases, which appear at low levels in poultry houses, on egg production. Many compounds have been identified in the atmosphere above poultry manure (Burnett, 1969b; Deibel, 1967). The compounds identified include butyric, acetic, propionic, and valeric acids also ethanol, acetone, indole, skatole, mercaptans, sulfides and aldehydes. It is likely that these compounds interact to form a "chicken house" odor. Measurement of these compounds is difficult due to their adsorption on dust particles and their volatility.

The problem generally associated with a "chicken house" odor is operator comfort rather than reduced egg production. For a commercial operation with hired labor, operator comfort can not be overlooked and it is reasonable to assume that if the operator is more comfortable then the birds are also in a more productive environment. The odor offensiveness of poultry houses has been measured with the aid of an odor panel (Hashimoto, 1972). A direct positive correlation was found between odor offensiveness and atmospheric ammonia concentrations. Atmospheric ammonia was not

the sole cause of offensive odors, but was a good indicator of the level of other odorous compounds. An atmospheric ammonia level of above 10 $\mu\text{g}/\ell$ is uncomfortable for an operator and the maximum allowable concentration for an operator is 35 $\mu\text{g}/\ell$ for 8 hours (North, 1972).

Atmospheric Ammonia Concentrations in Poultry Housing

After Bullis et al. (1950) postulated that atmospheric ammonia was a factor contributing to outbreaks of keratoconjunctivitis, he attempted to determine what factors in a poultry house caused increases in atmospheric ammonia concentrations. In the poultry houses that reported outbreaks of keratoconjunctivitis, one or more of the following conditions were noted: damp litter, low ventilation rates, water spillage problems, or old litter. Bullis assumed many of these factors were interrelated but had no data with which he could determine the interrelationships.

Longhouse et al. (1963) studied the effect of temperature, relative humidity, ventilation rate on atmospheric ammonia concentrations in poultry houses. They found that atmospheric ammonia concentrations did not vary with temperature in a range from 16°C to 35°C, when the relative humidity remained between 60% and 80%. However, relative humidities below 60% appeared to inhibit the concentration of atmospheric ammonia.

A direct relationship between ventilation rates and atmospheric ammonia concentrations was not determined in the Longhouse et al. study. However, they did find that higher ventilation rates had lower peak ammonia concentrations, which indicated that the effect

of ventilation rates on atmospheric ammonia concentrations was interrelated with other environment factors.

Longhouse et al. also noted that the moisture content of the litter must be kept below 20% or increased atmospheric ammonia concentrations resulted. No mention was made of the effect of temperature, relative humidity, or ventilation rate on the moisture content of the litter.

In 1964, Valentine studied the effect of different ventilation rates on the ammonia concentrations in the atmosphere of a broiler house. The experimental house used had been modified to provide 4 pens with an 2.4×4.3 m floor area. Each pen housed 120 birds, which were raised on a concrete floor with wood shavings. The birds were kept in the pens for 10 weeks during which time the wood shavings were not removed. Ventilation rates in the 4 pens were controlled to provide each pen with a different ventilation rate, 0.009, 0.019, 0.028, $0.038 \text{ m}^3/\text{min-bird}$. Supplementary heat was provided to maintain a constant temperature. His results suggest that ventilation rate is a principal factor affecting atmospheric ammonia concentration. However, any given atmosphere ammonia concentration may be produced by an interaction of temperature, humidity, and age of litter with the ventilation rate.

Valentine also found that atmospheric ammonia concentrations were closely related to the water vapor content of the air. His explanation of this relationship was that the ammonia was dissolved in the water vapor. This explanation was supported by test results that indicated the water vapor content of the air was most closely

related to atmospheric ammonia concentrations at high temperature when the water vapor holding capacity of the air is also higher and by the previously stated observation of Longhouse et al. (1963) that relative humidities below 60% appeared to limit the concentration of atmospheric ammonia.

Birds that were started on new wood shavings at one-day of age produced no detectable atmospheric ammonia until the 5th or 6th week in Valentine's study. From the time when atmospheric ammonia concentrations were first detectable until the end of the test (the 10th week), the atmospheric ammonia concentrations increased in every test. The increase in atmospheric ammonia concentration during the test paralleled the increase in fecal content of the litter so the relationship suspected by Bullis between age of the litter and atmospheric ammonia concentrations was confirmed.

Since an increase in the fecal content of the litter results in an increased atmospheric ammonia concentration, it would appear that more frequent removal of layer droppings should result in reduced atmospheric ammonia concentrations. This concept was tested in facilities which allowed the droppings from floor-managed layers to accumulate in pits under the feeders and roosts (Lampman et al., 1967). In one test facility, the droppings were removed from the pits twice weekly. In another similar facility, the droppings were allowed to accumulate in the pit for the entire length of the test. The average atmospheric ammonia concentration measured in the facility where the droppings were not removed was 3 times higher than that measured in the facility where the droppings were removed twice weekly.

Similar results were obtained by Ludington et al. (1971) in a test which compared five different manure storage and removal systems in terms of odor offensiveness, using an odor panel. The results showed that the odor offensiveness of layer droppings could be reduced by either of two methods. One was the reduction of the moisture content of the manure, which had been noted earlier by Longhouse et al. The other method was to remove the droppings daily from the layer house.

The tests of Ludington et al. (1971) included a comparison of two systems that allowed droppings to accumulate in pits under layer cages. One system allowed the droppings to accumulate in a pit without the addition of any water. In other systems, water was added at the beginning of the test. The test results showed a significant difference between the odor offensiveness of the two systems, with the system starting with water in the pit having the highest level of odor offensiveness. No attempt was made to keep the water level in the pit above the level of the accumulated droppings in this test.

In another test, Ludington et al. (1969) investigated the differences in gases produced by chicken manure stored and handled in the diluted and undiluted state. The study was conducted using two 19ℓ carboys (one for each system) to represent the manure collecting pits. Manure from laying hens was collected and fed daily to the carboys at a rate of 75 g per day. The undiluted system received its manure at 75% moisture content (w.b.) while the diluted system's manure was diluted 3:1 by weight with distilled water (94% moisture content w.b.). Air was passed over each carboy at $0.028 \text{ m}^3/\text{hr}$ and

then through gases analysis equipment.

With respect to gas production by the two systems, Ludington et al. found that manure stored in a diluted state produced significantly more ammonia and hydrogen sulfide than the undiluted storage system. However, since ammonia is highly soluble in water, the diluted system released less ammonia than the undiluted system.

The interrelationships between atmospheric ammonia concentrations, ventilation rates, and moisture content of the manure was studied by Kling and Bressler (1974). Since ventilation rates are largely dependent on the outside temperature during the winter, they included outside temperature in their multiple regression analysis. Their simple correlation comparing atmospheric ammonia concentration with each independent variable, ventilation rate, moisture content of the manure, and outside temperature, showed that each independent variable had a significant effect on the atmospheric ammonia concentration. A multiple regression analysis proved that when several independent variables were considered together, they explained significantly more of the variation in the atmospheric ammonia concentration than any independent variable considered alone.

To summarize, several environmental factors have been shown to effect atmospheric ammonia concentrations in poultry houses. These environmental factors include ventilation rate, moisture content of the manure, age of the litter, type of manure handling and storage and, to a lesser degree air temperature and relative humidity. As atmospheric ammonia concentration will be a result of an interaction of the above environmental factors, each poultry house will have

a concentration unique to that house, its management, its handling and storage system, etc.

Poultry Manure-Management Systems

Through the late 1950's, layers were commonly housed on concrete floors covered with litter. The litter was removed after each group of layers and spread on adjacent land. Egg producers were later forced to change the manure handling in their facilities, because as they increased the number of layers they raised, floor area per layer was simultaneously reduced below 1200 to 1900 cm²/bird, the litter became damp and the environment of the house deteriorated (North, 1972). To better accommodate an increase the number of layers without increasing the size of the building, producers began placing layers in wire cages. Cages allowed the floor area per layer to go as low as 390 cm²/bird without reducing egg production (Bell, 1972). For this reason, along with the increased automation of feeding and egg collection possible in caged-layer systems, use of caged-layer systems in the Midwest are now common.

The manure-management systems in caged layer houses can be divided into two general types, dry and liquid. Dry manure-management systems range from allowing the manure to pile in shallow pits under the cages to systems that mechanically remove the manure and then dry it for storage or reuse. Liquid manure-management systems most commonly allow the manure to collect in pits filled with water under the cages but in recent years other liquid systems have been developed.

Dry manure-management systems

Coning, allowing manure to pile under the cages, can be used

successfully in hot, arid regions, when proper management procedures are followed. These include keeping cage population down, preventing water spillage and overflow, having good air circulation under the cages, and leaving a pad of dry manure under the cages when cleaning (Ostrander, 1963). This system holds little promise for the Midwest because it does not work satisfactorily in totally enclosed buildings during the winter.

The coning system of manure management has been modified in order to make it feasible in more humid climates (Sobel, 1972). Devices have been installed below the cages which prevent the manure from immediately accumulating in a dense mass. These devices include fins placed at various angles beneath the cages and screens. The effect of placing fins at an angle below the cages is to increase the surface area over which the manure is distributed, which is equivalent to decreasing the bird density. Both fins and screens can reduce the moisture content of manure under cages but can have serious drawbacks because they require mechanical cleaning and add moisture to the ventilation air, a problem with any in-house drying system.

Another method which aids in the drying of manure under layers is the installation of fans and stirring mechanisms under the layers (Kling and Bressler, 1974; Sobel, 1972). The increased flow of air over the manure increases the rate of moisture removal. If the moisture is removed before more manure is deposited, then the manure should not stick together. Velocities above the manure in test installations have ranged from 46 to 457 m/min. The stirring mechanism generally used is a scraper cleaner which has been modified by installing small

teeth below the scraper, causing it to stir the manure while cleaning. In the test installations using this system, the moisture content of the manure has ranged from 60% to 20%.

Kling and Bressler (1974) showed that in a system as described above, the atmospheric ammonia concentration was related to the air-removal rate by

$$\text{NH}_3^a = 6.90 - 0.04X \quad (1)$$

where

NH_3^a = atmospheric ammonia concentration, $\mu\text{g}/\ell$

X = air removal rate, $\text{m}^3/\text{min-bird}$

To further promote drying during the winter for a flock of 3250 layers, Bressler (1968) installed a heat cable in the floor, below an installation of fans and stirring mechanisms. Even without the heat cable, the moisture content of the manure could be reduced to 30% in any season of the year at a daily electrical requirement of under 10 kWh. By operating the heat cable, the moisture content of the manure was reduced to less than 20% during all seasons. The daily electrical requirement increased sharply with the use of the heat cable to over 60 kWh. Since atmospheric ammonia levels were directly related to the moisture content of the manure, Equation 2, it is important that the moisture content of the manure be kept as low as possible (Kling and Bressler, 1974).

$$\text{NH}_3^a = 1.36 + 0.05 \text{ MC} \quad (2)$$

where

NH_3^a = atmospheric ammonia concentration, $\mu\text{g}/\ell$

MC = moisture content, %

Most in-house drying systems for manure management require the cages be arranged in a stairstep or modified stairstep arrangement, which limits the possible bird density. In a housing system evaluated at West Virginia University, the cages were mounted vertically as shown in Figure 3 (Longhouse, 1972). Below each row of cages is a dropping board which is scraped mechanically once or twice daily. With the cage arrangement shown in Figure 3, an increase in the layer population of 100% is possible over a three-row, two-tier stairstep arrangement by the use of four rows, three tiers high. The amount of mechanical equipment for manure removal used by this system may limit its usefulness in commercial operations.

The possibility of refeeding dried poultry feces has increased the interest in dry manure systems. Extensive research has been conducted at Michigan State University on drying poultry feces and refeeding it to layers (Surbrook et al., 1971; Flegal and Zindel, 1971; Gerrish et al., 1973). Their manure-handling system consists of trays that are scraped mechanically to one end of the building, a gutter cleaner to collect the manure and deposit it on a drying belt, and a commercial dryer. As the ventilation air leaves the building, it passes over the drying belt to provide some predrying before entering the dryer.

Layer diets which contained up to 20% dried poultry manure did not significantly reduce egg production and feed efficiency (Flegal and Zindel, 1971). When dried poultry manure is included in a layer ration as 20% of the ration, 58% of the manure production will be utilized as feed. However, layer diets containing dried

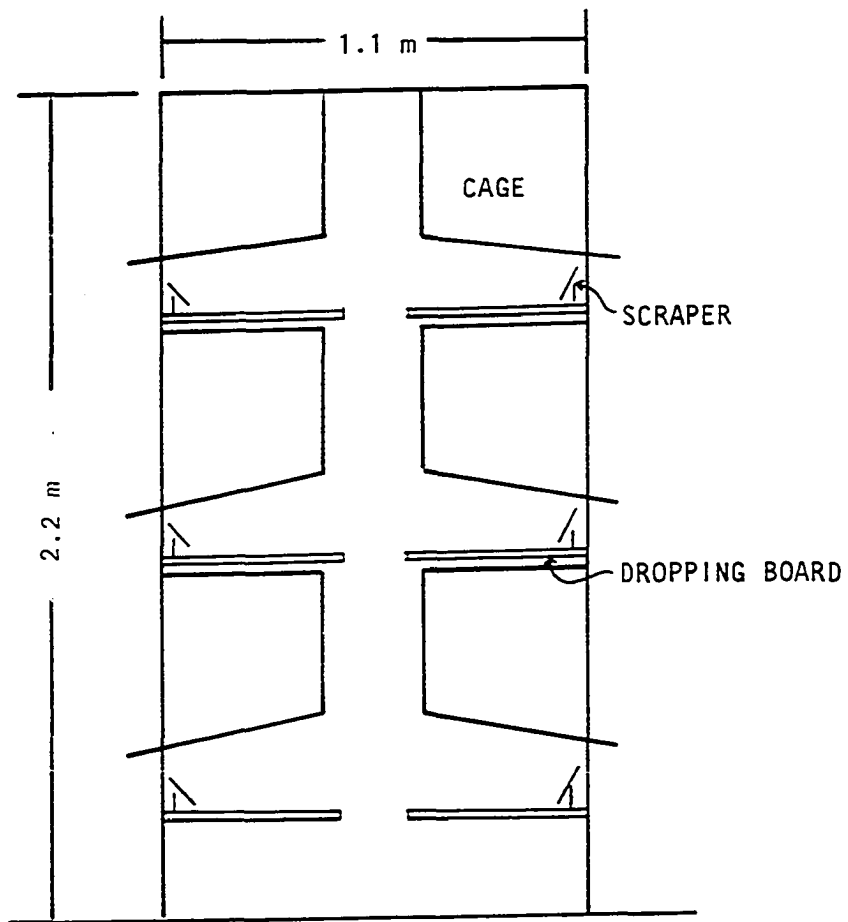


Figure 3. Vertical cage arrangement used with mechanical scrapers (Longhouse, 1972)

poultry manure have not been approved for commercial use by the Food and Drug Administration. Drying one ton of 75% moisture content poultry manure to 10% moisture content with a commercial dryer required 25 kWh of electricity, 54 gal of fuel oil, and 0.7 hr of labor (Surbrook et al., 1971).

Manure removed from dry manure-management systems can be either field spread or processed further. Field spreading of partially dried manure is the most common method of final manure disposal used with dry systems. By drying manure to about 30% moisture content inside the poultry house, the weight and volume of manure to be handled can be reduced to about 1/3 of the original amount (Bressler, 1968). Two methods tried for further processing have been composting and incineration (Forsht et al., 1974). In the composting process the volatile solids in the fecal matter are digested by aerobic microorganisms. A stable, inoffensive material which has a lower weight and reduced volume than the original material is produced by composting. The composting process requires controlled moisture, temperature, and aeration conditions. The combustible fractions of the manure are burned during incineration leaving only the mineral matter as an ash. Substantial volume and weight reductions result from incineration. Predrying of poultry manure may be required before incineration because the manure's initial moisture content prevents the use of most presently available incinerators. Both of these methods are technically feasible but are presently expensive methods of treatment when one considers that they are not final disposal operations.

Liquid manure-management systems

Since the early 1960's, the use of pits, which contain water, has become a common poultry manure-collection system. The main advantages of a liquid pit collection system include: flexibility in time of cleaning, less mechanization, temperature control in the poultry house, and reduced odors (Ostrander, 1964).

Flexibility in the schedule of cleaning is a major advantage of liquid pit systems (Ludington and Sobel, 1964). With proper design, pits may require cleaning only two or three times per year. This allows the producer who field-spreads liquid manure to choose times when conditions for field-spreading are good for cleaning. Figure 4 shows the rate of solids accumulation in a liquid pit at various bird densities (Ludington and Sobel, 1964). The variation in the rate of solids accumulation is due to differences in pit cleaning and dilution used by the commercial operators which furnished the data.

Liquid pit systems reduce, but do not eliminate, the requirement of mechanical equipment. Since poultry manure settles rapidly, it is necessary to provide a method of mixing and moving the solids to the drain. It is possible to combine the mixing and moving functions with the use of a fire hose or water propelled scrapers. Water propelled scrapers have worked successfully in systems where the scrapers are pushed by recycled water from settling pits (Witz et al., 1969; Johnson, 1964).

The volume of water in a liquid pit system helps to control the air temperature in a layer house during sudden changes in outside

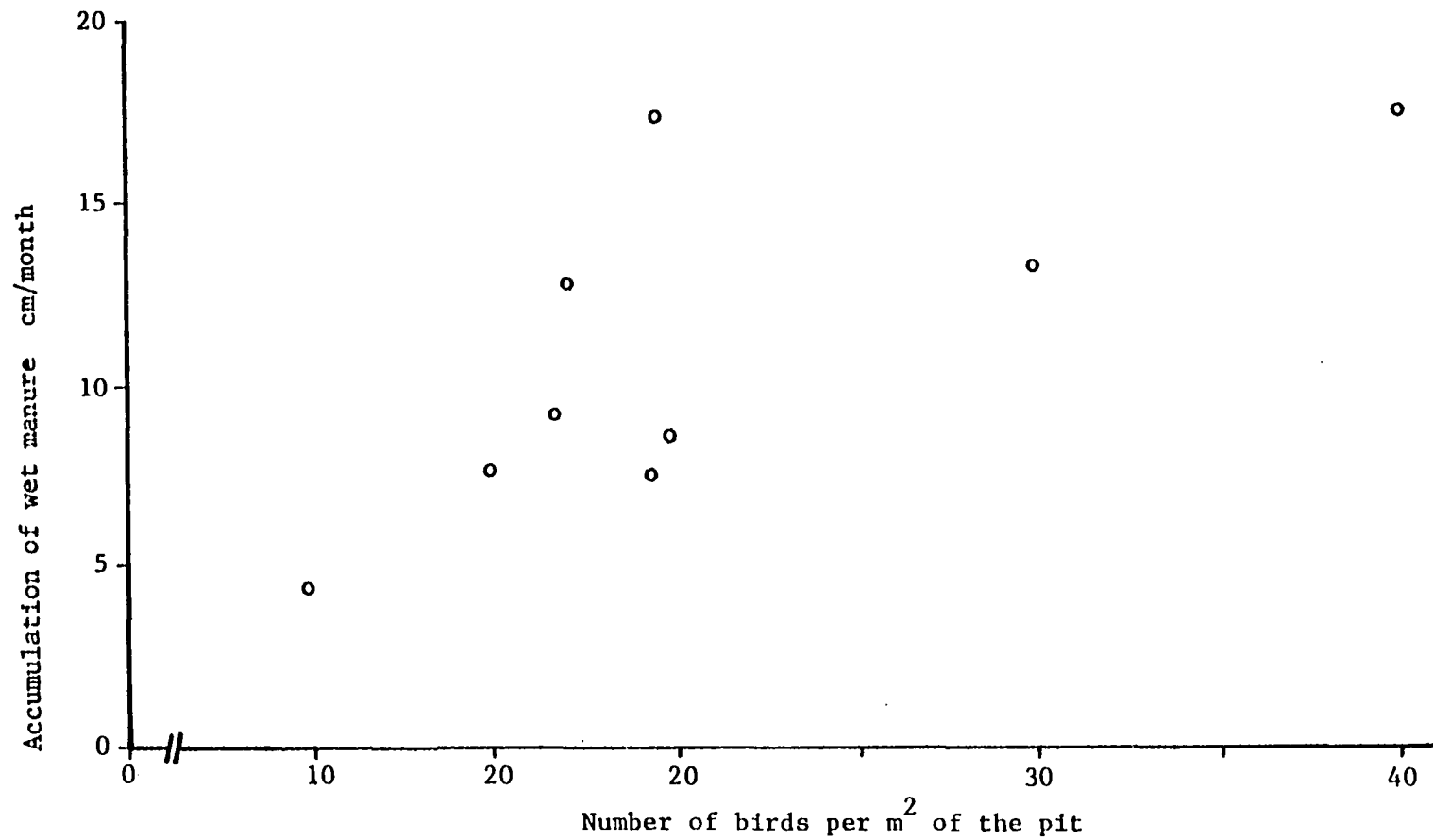


Figure 4. Solids accumulation in shallow pits under laying hen cages at various bird densities (Adapted from Ludington and Sobel, 1964)

temperature (Ostrander, 1964; Adams, 1964). Producers have noted that liquid-pit buildings remain warmer for a period of time during a cold snap. The building may be maintained at a warmer temperature for 3 or 4 days or until the pit temperature drops. Temperature modification will vary with pit volume, pit temperature and ventilation rate.

When the solids' level in a liquid pit are not allowed to build up above the water level, odors will be reduced (Ostrander, 1964). As earlier mentioned, liquid storage of poultry manure results in increased ammonia production but decreased ammonia release due to the solubility of ammonia (Ludington et al., 1969). It is possible that the ammonia concentration of the liquid in the pit may increase until desorption occurs; however, if the solids are to remain covered, water must be added continually while the pit is filling. There appears to be a slight amount of bacterial action which produces gas but its effect on the environment is minimal (Ostrander, 1964).

In order to further reduce odor levels in layer houses, research has been conducted to determine if it is feasible to keep the pit liquid aerobic (Walker and Pos, 1969; Hashimoto, 1972). The two basic methods of aerating the pit liquid tested have been rotors, which lift the water into the air, and diffused-air aeration systems, which pump air into the water. While both methods were able to maintain an aerobic pit liquid, they both experienced problems with foam accumulation on the surface of the pit liquid. The foam accumulation was aggravated by feathers, particularly during moults;

therefore, the feathers had to be skimmed off regularly. Rotors have experienced mechanical problems with the bearings and drive system, due to the highly corrosive atmosphere and pit liquid. Regular cleaning of the diffused air aeration system is required to prevent plugging due to crystal buildup. The daily power requirement of an aerated system has been estimated at 0.021 kWh per laying hen (Jones et al., 1971).

Liquid-manure-handling systems have been built which remove the manure frequently from a layer house (Johnson, 1964; Witz et al., 1969; Dugan et al., 1972). Early systems used water propelled scrapers which were pushed down the pits by pumping water behind the scrapers (Johnson, 1964; Witz et al., 1969). After cleaning, the scraper was lifted out of the pit and carried to the upper end of the pit. To reduce the amount of water used by these systems, the water and manure used to push the scrapers entered a 4-cell holding chamber where the manure settled out and the water was recycled into the building. Odor problems developed in the summer in the recycled water but could be corrected by the addition of alum or aeration of the fourth cell. The daily requirement for cleaning the pit is approximately 0.071 kWh per 1000 layers and 0.083 hrs of labor per 1000 layers.

A pilot-plant system has been tested which was designed for 140 layers, using water to clean sloping trays without the aid of a scraper (Dugan et al., 1972). The fiberglass-coated plywood trays installed below the cages were cleaned each hour by water from tipping buckets at the highest end of each tray. Manure flushed from the

trays was passed through a sedimentation tank, then the supernatant was treated in an algae pond and the solids were digested anaerobically. Effluent from the algae pond was used as recycled water for flushing the trays.

Manure removed by liquid-manure-management systems is generally either field spread or decomposed in lagoons and then field spread. To pump liquid manure, the moisture content should be above 85% (Ostrander, 1964). In order to raise the moisture content of fresh manure to this level, it must be diluted with an equal volume of water, resulting in double the volume of material to be handled. If a high percentage of the manure is decomposed in a lagoon, the effluent may be irrigated onto cropland as a final disposal method. Recent increases in energy costs have caused researchers to consider anaerobic digestion of poultry wastes for the production of methane as a possible use of liquid manure. Full-scale commercial units must be tested to determine if anaerobic digestion is economically feasible.

Ammonia Desorption from Liquid Manure

If a soluble gas is exposed to a solvent, exchange will take place between the gas and the liquid until the partial pressure of the gas in the atmosphere equals the partial pressure of the gas dissolved in the liquid. When poultry manure is stored in a liquid manure system, the gas of major interest is usually ammonia. Although interchange between the ammonia in the atmosphere and the ammonia in the manure does depend upon the relative partial pressures, pH is also involved because dissolved "ammonia" exists both as ammonia,

NH_3 , and ammonium, NH_4^+ . The ammonium ion is not volatile. Mathematically simple equilibrium relations for ammonia in water at various pH values may be derived from basic chemistry but the relations expressing the kinetics of gas exchange in a field situation are usually too complex to be expressed mathematically without resorting to empirical factors.

When the partial pressure of a gas in the atmosphere exceeds that in the liquid, the gas will be dissolved or "absorbed" by the liquid. The reverse process of a gas in a liquid having a greater partial pressure is usually encountered for ammonia in wastes. In this instance, ammonia is evolved or "desorbed" from the liquid. The majority of the work reported in the literature deals with absorption, but Lewis and Whitman (1924) indicated the same factors control both absorption and desorption.

The desorption phenomenon can be described by the equations, (Figure 5)

$$\frac{dw}{dt} = Ak_g (p_i - p_g) \quad (3)$$

and

$$\frac{dw}{dt} = Ak_L (c_L - c_i) \quad (4)$$

where

$\frac{dw}{dt}$ = rate of desorption, g/hr

A = surface area of the liquid-gas interface, cm^2

k_g = diffusion coefficient through a gas film, $\text{g/hr-cm}^2\text{-atm}$

k_L = diffusion coefficient through a liquid film, cm/hr

p = partial pressure of ammonia in the atmosphere, atm

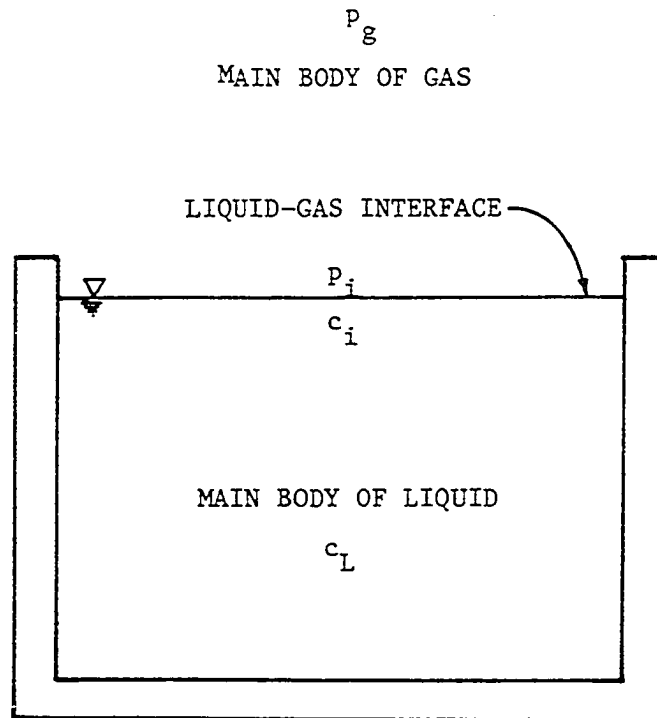


Figure 5. Diagram of the physical relationship between the terms in the desorption equations

c = concentration of ammonia in the liquid, g/cm^3

Subscript g applies to conditions in main body of gas

Subscript i applies to conditions at liquid-gas interface

Subscript L applies to conditions in the main body of liquid

Halsam et al. (1924) have shown that, in the case of ammonia desorption, both k_g and k_L are affected by ambient conditions. When the velocity of a gas increases over the liquid-gas interface, it decreases the thickness of the gas layer at the liquid-gas interface and, as a result, the diffusion coefficient, k_g , increases. Temperature has been shown to affect both k_g and k_L . The effect of gas velocity and temperature on k_g is given in Equation 5, and the effect of temperature on k_L is given in Equation 6.

$$k_g = 5,310 (0.3048V)^{0.8} (273 + T)^{-1.4} \quad (5)$$

$$k_L = 5.1 \times 10^{-7} (273 + T)^4 \quad (6)$$

where

V = velocity of the gas above the liquid-gas interface, m/min

T = temperature, $^{\circ}\text{C}$

An erroneous conclusion can be determined about the ammonia diffusion coefficient by considering only Equation 5. By substituting the value of zero for the velocity in Equation 5, the resulting diffusion coefficient for the gas layer is zero. This result is impractical when consideration is given to the natural diffusion of gases due to the differences in gas concentrations. Kowalke et al. (1925) indicated that the diffusion coefficient for an ammonia-air mixture being absorbed from still air at 20°C ranged from .036 to .048 $\text{g/hr-cm}^2\text{-atm}$. Taking a mean value of .042 $\text{g/hr-cm}^2\text{-atm}$,

it appears that 0.003 m/sec may be the lowest velocity that should be used with Equation 5. Data collected by Srinath and Loehr (1974) on the desorption coefficient of ammonia from a solution at zero air flow, $.038 \text{ g/hr-cm}^2\text{-atm}$, agrees well with Kowalke et al. results. The agreement between Kowalke et al. and Srinath and Loehr also validates the assumption that desorption and absorption are directly related phenomena.

Desorption in any system is controlled by the process of diffusion, either the diffusion of the gas through the surface-gas layer or the surface-liquid layer. The controlling layer is determined by which rate of diffusion is the slower. If the diffusion rate of both layers is approximately the same, both layers will have to be considered. Ammonia desorption is predominantly controlled by its rate of diffusion through the gas layer (Lewis and Whitman, 1924). When the effects of gas velocity and temperature are considered, an overall coefficient for the gas layer may be determined incorporating both k_g and k_L (Halsam et al., 1924).

In order to determine an overall coefficient combining both k_g and k_L pressure and concentration units must be reconciled. This can be accomplished by the use of Henry's Law (Equation 7).

$$c = H p \quad (7)$$

where

c = concentration of ammonia in the liquid, g/cm^3

p = partial pressure of ammonia in the atmosphere, atm

H = Henry's constant, $\text{g/cm}^3\text{-atm}$

Henry's Law can be applied at the ammonia levels found in this research

according to a graph shown by Treybal (1955). However, Mantell (1951) indicated that Henry's Law is a limiting value toward which things tend, and is not applicable over a wide range of concentrations. The concentrations encountered in this research did not vary greatly; therefore, the assumption that Henry's Law is valid will be used in further calculations.

Henry's constant varies with both temperature and the concentration of ammonia in the liquid. A graph shown by Halsam et al. (1924) indicates that at the range of concentrations of ammonia found in this research, Henry's constant does not vary appreciably. A graph shown by Treybal (1955) also supports this conclusion. Figure 6 shows the variation of Henry's constant for ammonia in water with temperature change and the power curve fitted to the data (Weast, 1971). Henry's constant for ammonia in water can be estimated by Equation 8.

$$H = 2.888 e^{-.0428T} \quad (8)$$

where

$$T = \text{temperature, } ^\circ\text{C}$$

In order to develop an overall coefficient for the gas layer, it is necessary to assume that the concentration of ammonia in the liquid at the liquid-gas interface is equal to the concentration of ammonia in the main body of the liquid and that p_i and c_i at the liquid-gas interface are in equilibrium (Figure 5). With the aid of Henry's Law, this allows Equation 3 to be written in the form,

$$\frac{dw}{dt} = AK_g (p_L - p_g) \quad (9)$$

where

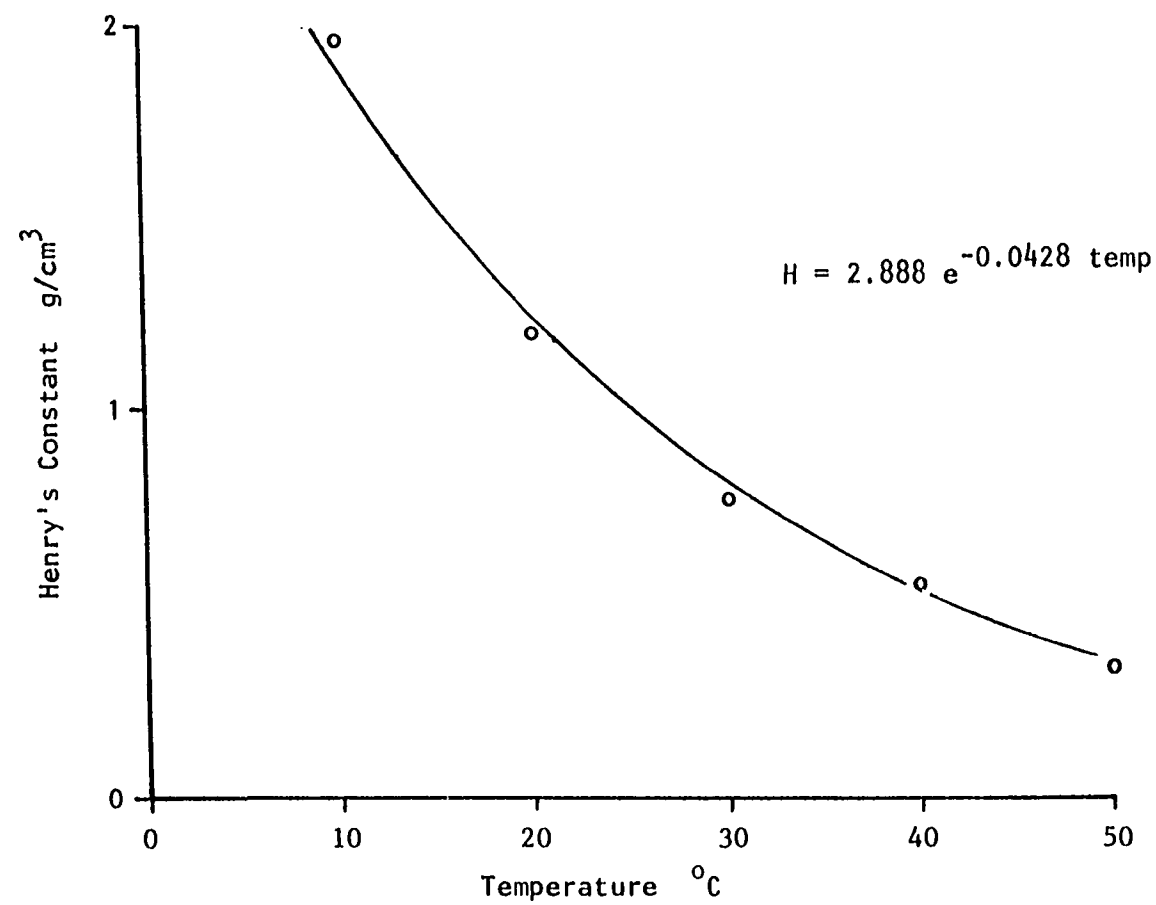


Figure 6. The variation in Henry's constant for ammonia in water with temperature

K_g = overall diffusion coefficient for the combined layers,
g/hr-cm²-atm

and by combining Equations 3, 4, 9, K_g can be determined from k_g and k_L (Equation 10).

$$K_g = \frac{Hk_L k_g}{Hk_L + k_g} \quad (10)$$

In the ammonia desorption equation, the only remaining terms to be considered are the partial pressures of ammonia in the main body of the air and at the liquid-gas interface. The partial pressure of ammonia in the main body of the air is related to the measured concentration of ammonia gas in the air (as mass/unit volume of air). Factors affecting the partial pressure of ammonia in the air include the concentration of ammonia gas in the air, the air temperature, and the relative humidity of the air. These factors can be related by the use of Dalton's Law of partial pressure and the ideal gas law (Equation 11).

$$P_g = \frac{(NH_3^a) (SVA) (28.97) (28.32)}{(4.54 \times 10^8) (17.03)} \quad (11)$$

where

P_g = partial pressure of ammonia in the air, atm

NH_3^a = concentration of ammonia in the air, $\mu\text{g}/\ell$

SVA = specific volume of the air, ft^3/lb

28.97 = weight of air per mole, g/mole

28.32 = conversion factor, ℓ/ft^3

4.54×10^8 = conversion factor, $\mu\text{g}/\text{lb}$

17.03 = weight of ammonia per mole, g/mole

Figure 7a is a graphical representation of Equation 11 and allows P_g to be determined more rapidly with little loss of accuracy. The conversion factor C relates the concentration of ammonia in the air to the partial pressure of ammonia in the air (Equation 12).

$$P_g = C(NH_3^a)$$

where

$$C = \text{conversion factor, atm- } \ell/\mu\text{g}$$

Research has shown that the pressure of ammonia at the liquid-gas interface can be approximated by the pressure of the ammonia in the main body of the liquid (Halsam et al., 1924; Lewis and Whitman, 1924). One method of determining the pressure of ammonia in a liquid is with the use of Henry's Law (Equation 7).

Kowalke et al. (1925) developed an equation (13) to determine the partial pressure of ammonia. The equation was developed for standard conditions and 25°C.

$$P_L = \frac{NH_3^L}{17,000} e^{\frac{-4425}{273 + T}} + 10.82 \quad (13)$$

where

P_L = pressure of ammonia in the main body of the liquid, atm

NH_3^L = concentration of ammonia in the liquid, mg/ ℓ

T = temperature, °C

Equation 13 assumes that Henry's Law holds over the range of temperatures and concentrations that Equation 13 applies to and that the heat of solution of ammonia is independent of temperature. However, the assumption that the heat of solution of ammonia is independent of temperature is valid only for a small temperature range. Figures

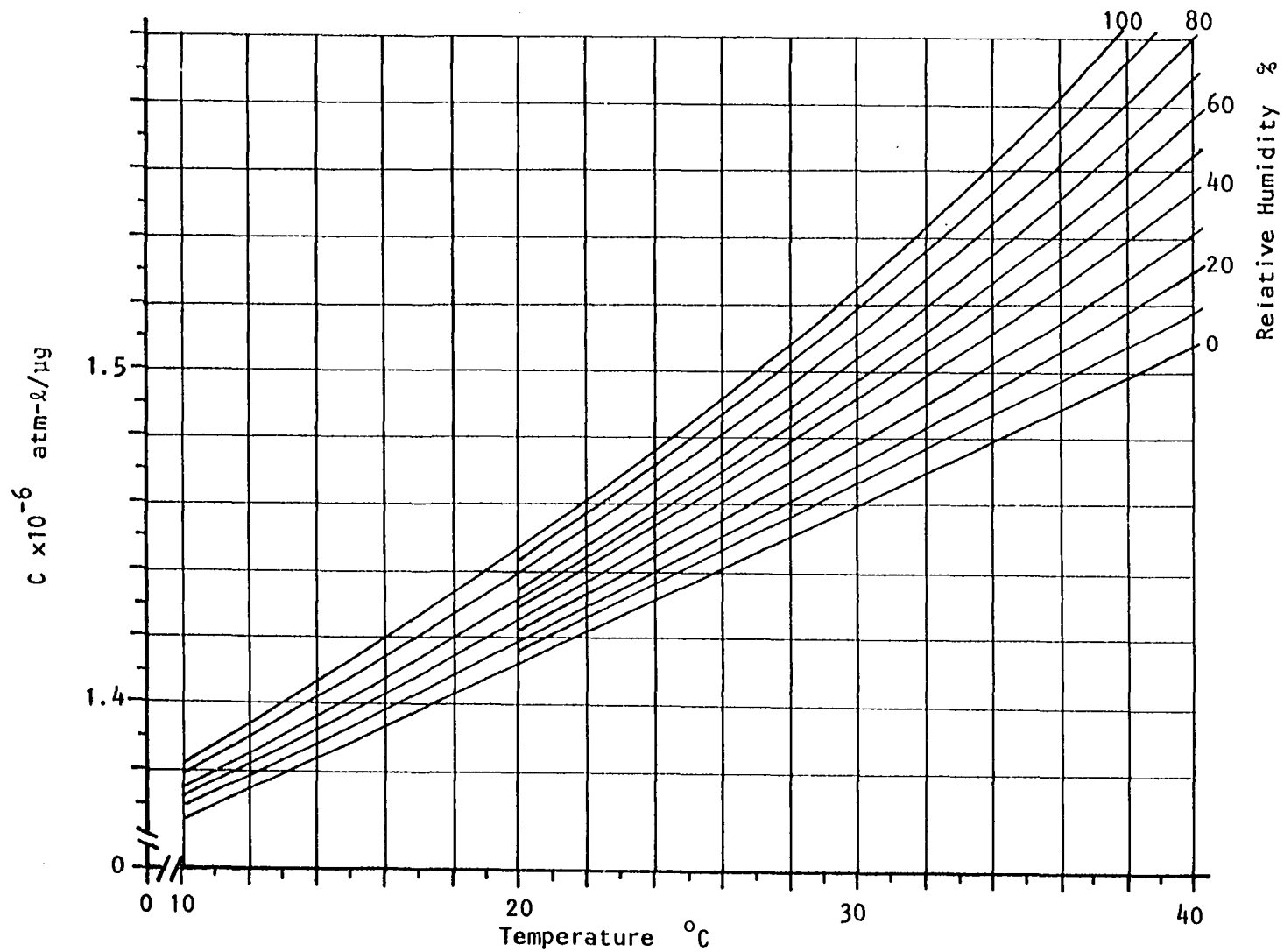
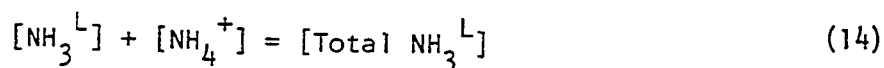


Figure 7a. The effect of temperature and relative humidity on the conversion factor (C) relating the concentration of ammonia to the partial pressure of ammonia in the air

shown by Kowalke et al. indicate that Equation 13 is accurate for low concentrations of ammonia in solution over the temperature range 15 to 35°C. Therefore, Equation 13 will be used in further calculations to determine the pressure of ammonia in the air at the liquid-air interface.

It is difficult to determine either the ammonia or ammonium concentration analytically in a solution containing both forms. The standard procedure is to measure the total ammonia nitrogen present by converting the ammonium ions to ammonia at a high pH (Equation 14).



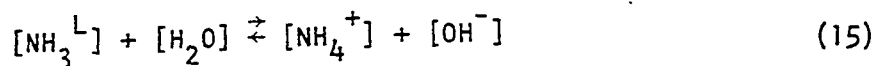
where

$[\text{NH}_3^{\text{L}}]$ = ammonia concentration in a liquid, moles/l

$[\text{NH}_4^{+}]$ = ammonium concentration in a liquid, moles/l

However, it is necessary to know the ammonia concentration in a liquid because ammonium ion concentration has no direct effect on ammonia desorption.

In order to determine the ammonia concentration in a liquid, it is necessary to know the equilibrium equation describing ammonia dissociation in water (Equation 15).



At equilibrium, the dissociation obeys Equation 16.

$$\frac{[\text{NH}_4^{+}] [\text{OH}^{-}]}{[\text{NH}_3^{\text{L}}]} = K_b \quad (16)$$

where

K_b = dissociation constant for aqueous ammonia

OH^- = hydroxide ion concentration

The fraction of ammonia in an aqueous solution can now be determined by combining Equations 14 and 16 (Equation 17).

$$F = \frac{[\text{NH}_3^L]}{[\text{NH}_3^L] + [\text{NH}_4^+] } = \frac{1}{1 + \frac{K_b}{\text{OH}^-}} \quad (17)$$

where

F = ammonia fraction in an aqueous solution

Since it is not common to measure hydroxide ion concentrations, Equation 17 can be modified using the ionization constant for water (Equation 18) and relationship between the hydrogen ion concentration and pH. (Equation 19).

$$[\text{H}^+] [\text{OH}^-] = K_w \quad (18)$$

where

K_w = ionization constant for water

H^+ = hydrogen ion concentration

$$\text{pH} = -\log_{10} [\text{H}^+] \quad (19)$$

The modified Equation 20 uses the more common pH measurement to determine the ammonia fraction in an aqueous solution.

$$F = \frac{1}{1 + \frac{K_b}{K_w} 10^{-\text{pH}}} \quad (20)$$

Both K_b and K_w are dependent on temperature, which may be accounted for by the empirical relation in Equation 21 (Daniels and Alberty, 1967).

$$K = Ae^{B/T} \quad (21)$$

where

K = equilibrium constant

A and B = constants

T = temperature

Equation 22 was derived by regression, using handbook values to approximate the change in K_b/K_w with temperature. (Figure 7b) (Weast, 1971).

$$\frac{K_b}{K_w} = 1.219e^{\left(\frac{6284}{273 + T}\right)} \quad (22)$$

where

T = temperature, $^{\circ}\text{C}$

Hashimoto and Ludington (1971) conducted experiments to determine if the acid ionization constants for ammonia given in handbooks were accurate for the poultry manure slurry. The acid ionization constant for ammonia is related to K_b/K_w by Equation 23.

$$K_a = \frac{K_w}{K_b} \quad (23)$$

They concluded that the actual acid ionization constants for ammonia in a poultry-manure slurry were about one-sixth of the published values for a dilute solution of anhydrous ammonia.

By comparing values calculated using Equations 20 and 22 with those calculated from the results of using Hashimoto et al., it can be determined that at 10°C a reduction of over 80% in the ammonia fraction occurs up to a pH of 10. As the pH increases, the effect of a reduced ionization constant on the ammonia fraction would have little effect since it rapidly approaches 1.0, as shown in Figure 8. Figure 8 was developed by simultaneously solving Equations 20 and 22.

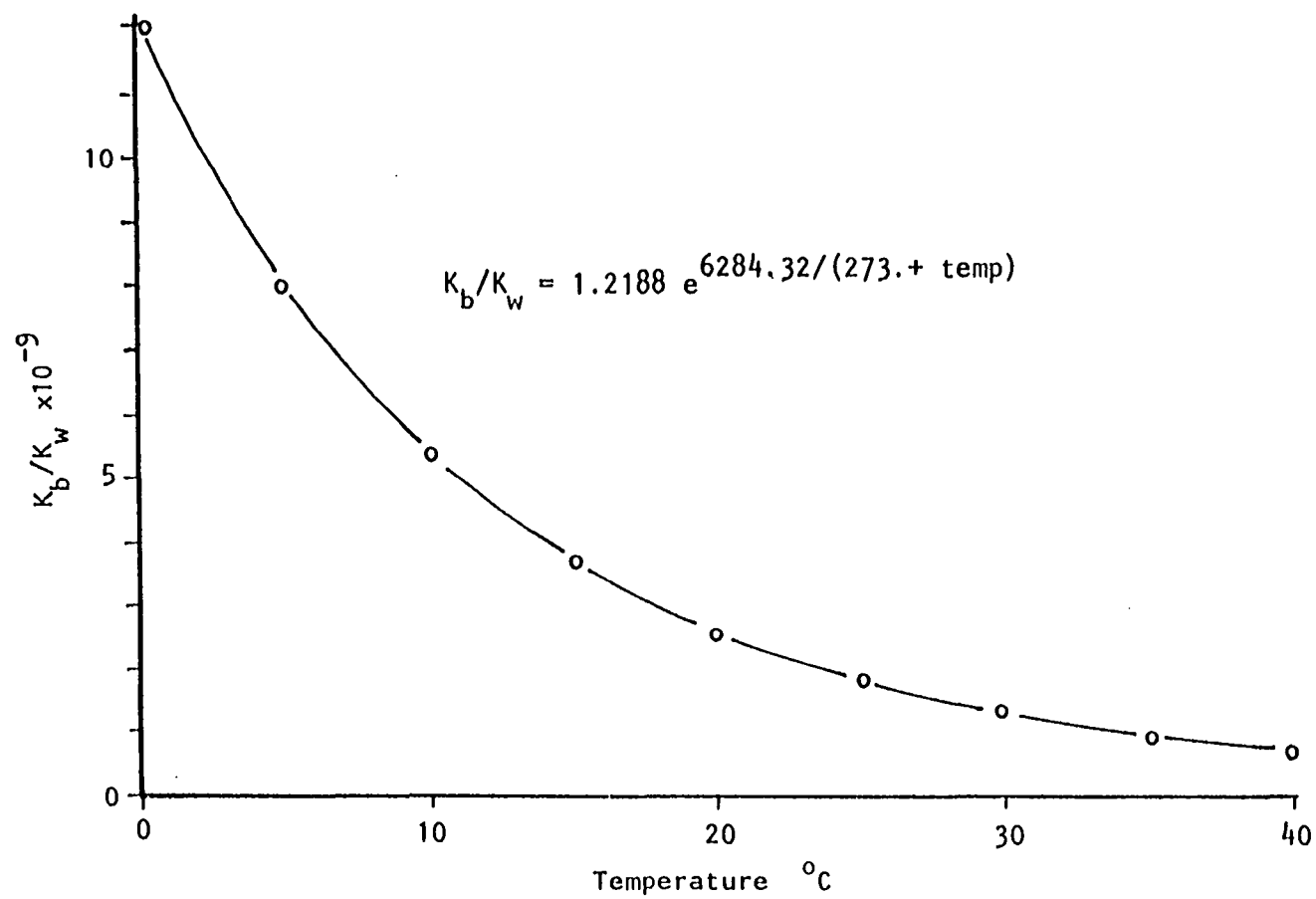
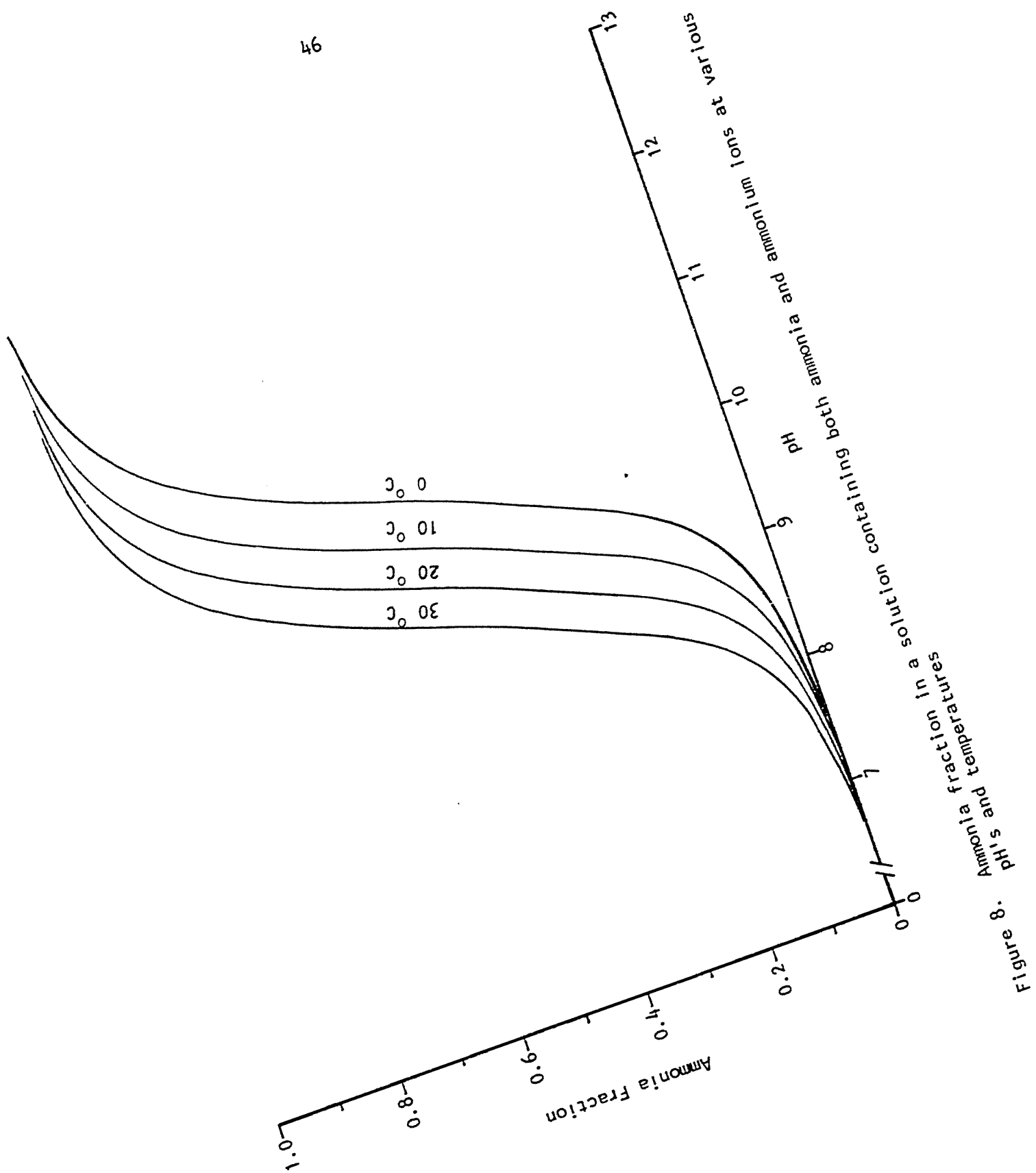


Figure 7b. The change in the ratio K_b/K_w with temperature



Hashimoto et al. experiments were conducted at higher pH values, total solids, and nitrogen concentrations than those experienced in this research. Therefore, Equations 20 and 22 will be used to determine the ammonia fraction of solutions in further calculations to determine the concentration of ammonia in a solution (Equation 24).

$$\text{NH}_3^L = (F) (\text{NH}_3 - \text{N}) (1.21) \quad (24)$$

where

NH_3^L = concentration of ammonia in the liquid, mg/l

$(\text{NH}_3 - \text{N})$ = concentration of total NH_3 as nitrogen in the liquid, mg/l

1.21 = conversion factor, NH_3 as nitrogen to NH_3 as ammonia

Economics of Manure-Management Systems

When evaluating the economics of any manure-management system, consideration must be given to both fixed and variable costs. Annual fixed costs include depreciation, interest on investment, insurance and taxes. Depreciation and interest on investment will be the fixed costs of most concern when comparing manure-management systems. Systems which require a lower initial investment in manure-handling equipment and have a longer operating life will reduce annual fixed costs. A system which allows the bird density of a building to increase will reduce the initial investment in buildings and therefore reduce annual fixed costs. The annual cost of insurance and taxes will vary with location; however, since they are generally estimated as a percentage of the initial investment, any reduction in initial investment will also reduce these fixed costs. The land required for final manure disposal should be included in the initial investment.

The annual variable costs of a manure-management system include fuel, electricity, labor, and repairs or maintenance. Systems described in the literature seldom include an economic analysis; however, some authors report annual variable costs. Table 1 indicates the

Table 1. The annual operating requirements of various poultry manure management systems.

System	Operating requirements /bird-yr	Source
Undercage drying		
Static	0.068 kWh	Ludington, 1970
Forced air	6.37 "	" "
Forced air + stirring	1.01 "	Bressler, 1968
Forced air + stirring + heat cable	4.5 "	" "
Commercial dryer	1.0 "	Surbrook et al., 1971
.....	2.0 & fuel	" " "
.....	0.028 hr labor	" " "
Flush - moveable dam	0.026 kWh	Johnson, 1964
.....	0.03 hr labor	" "
Oxidation ditch	7.67 kWh	Jones et al., 1971
.....	9.7 "	Martin et al., 1974

annual variable costs of systems described in the literature in terms of operating requirements (kWh, & of fuel, and hr of labor) on a per-bird basis, the actual cost of these items has increased significantly in the past year and may continue to do so in the future. The operating requirements given in Table 1 do not include final-disposal requirements.

Estimates of construction, equipment, and operating costs are not easily obtained for the variety of manure-management systems that must be compared by an egg producer. The system which has the lowest total annual cost, fixed plus variable, many not provide the most desirable environment for egg production and may require

more capital investment than the producer can afford. Other factors, such as legislation and labor scarcity, will affect a producer's decision concerning which manure-management system to adopt.

A general indication of the initial investment required for various poultry manure-management systems has been calculated at North Carolina State University (North Carolina Extension Service, 1973). According to these calculations, systems which direct-spread manure in the solid form require an investment of \$1 per bird; systems which hydraulically flush manure into lagoons and then irrigate and spread the lagoon effluent require an investment of \$1.30 per bird; systems which store and spread liquid manure require an investment of \$0.80 per bird, and systems which flush into aerator lagoons and then irrigate the lagoon effluent require an investment of \$1.10 per bird. These costs are very rough estimates and do not include the cost of the building or the land required for final manure disposal. By comparison, the 1975 cost of an insulated poultry building may range from \$65 to \$86 per m^2 , excluding cages and equipment; therefore, a manure-management system which reduces the floor area required per bird can have a higher initial investment per bird and still be the most economical in terms of total initial investment.

EXPERIMENTAL INSTALLATION

Description of Unit D

The Unit D egg-production house located at the Poultry Research Center, Iowa State University, was constructed in 1964. The house is divided into two similar wings which are separated in the center of the building by a service room (Figure 9). Twelve rows of individual cages, in 3 stairstep configurations, were installed in each wing (Figure 9, Figure 10). Beneath each stairstep of cages, a pit was constructed for liquid storage of the manure. The pits were 162 cm wide, 24 m long, and a minimum of 30 cm deep, with the floor sloped to a drain at the center of each pit.

A negative-pressure ventilation system was installed, comprised of a continuous-slot inlet along the sidewalls (Figure 11) and 3 exhaust fans in each wing. Two of the fans are two-speed units controlled individually by two-stage thermostats. A smaller fan is used for continuous operation during the winter. Because of the low stocking density of this building, a supplemental heater is required for winter ventilation. The heaters are located in the walls between the service area and each wing.

In the fall of 1972, remodeling began on the manure-handling system in the east wing of Unit D. The liquid-storage system was replaced by a flushing-gutter manure-handling system. The flushing-gutter system included in-house recycling, effluent treatment, and effluent recycling (Figure 12). Because of the remote lagoon location, 610 m, and restricted sewer slope, 0.6%, an in-house recycling system

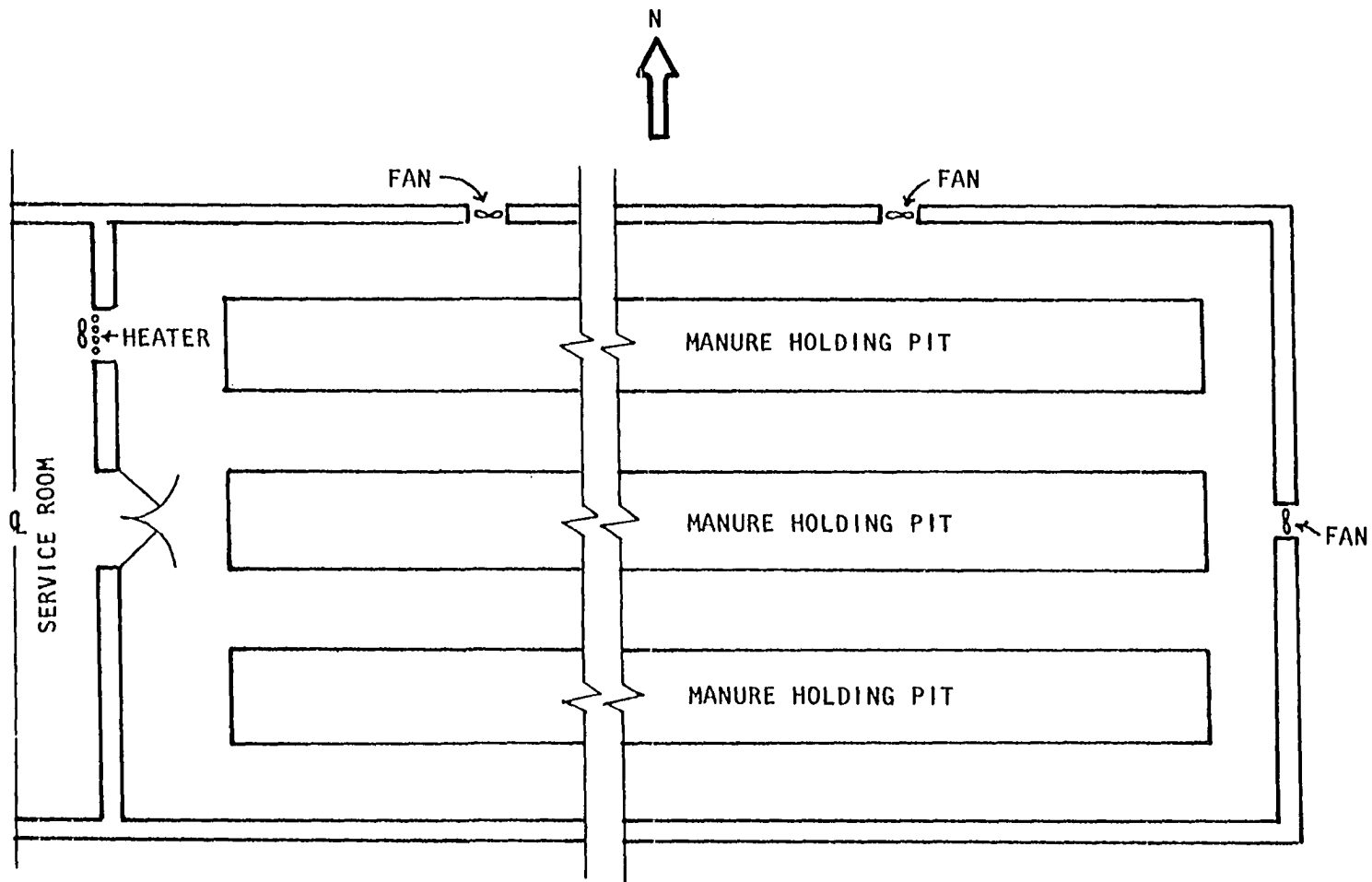


Figure 9. Floor plan of Unit D

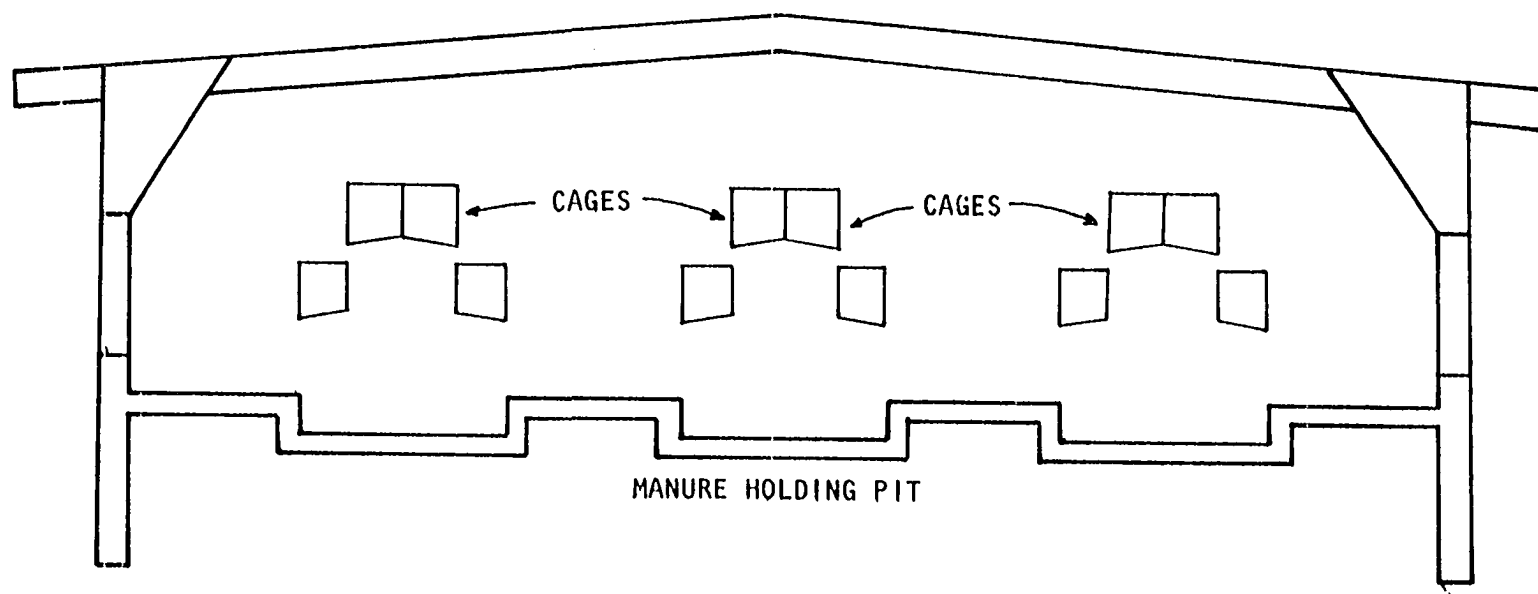


Figure 10. Cross-section of Unit D before remodeling

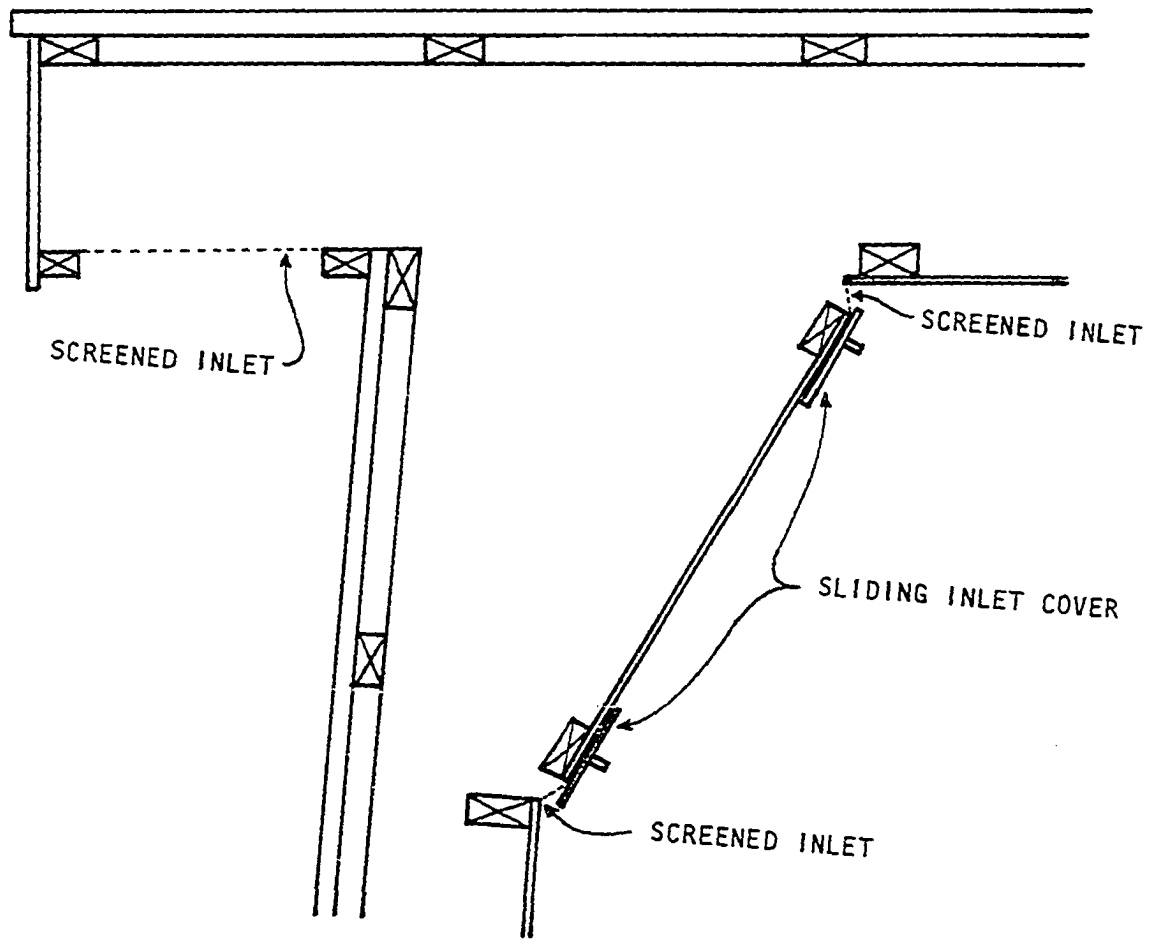


Figure 11. The continuous-slot air inlets along the sidewalls at Unit D

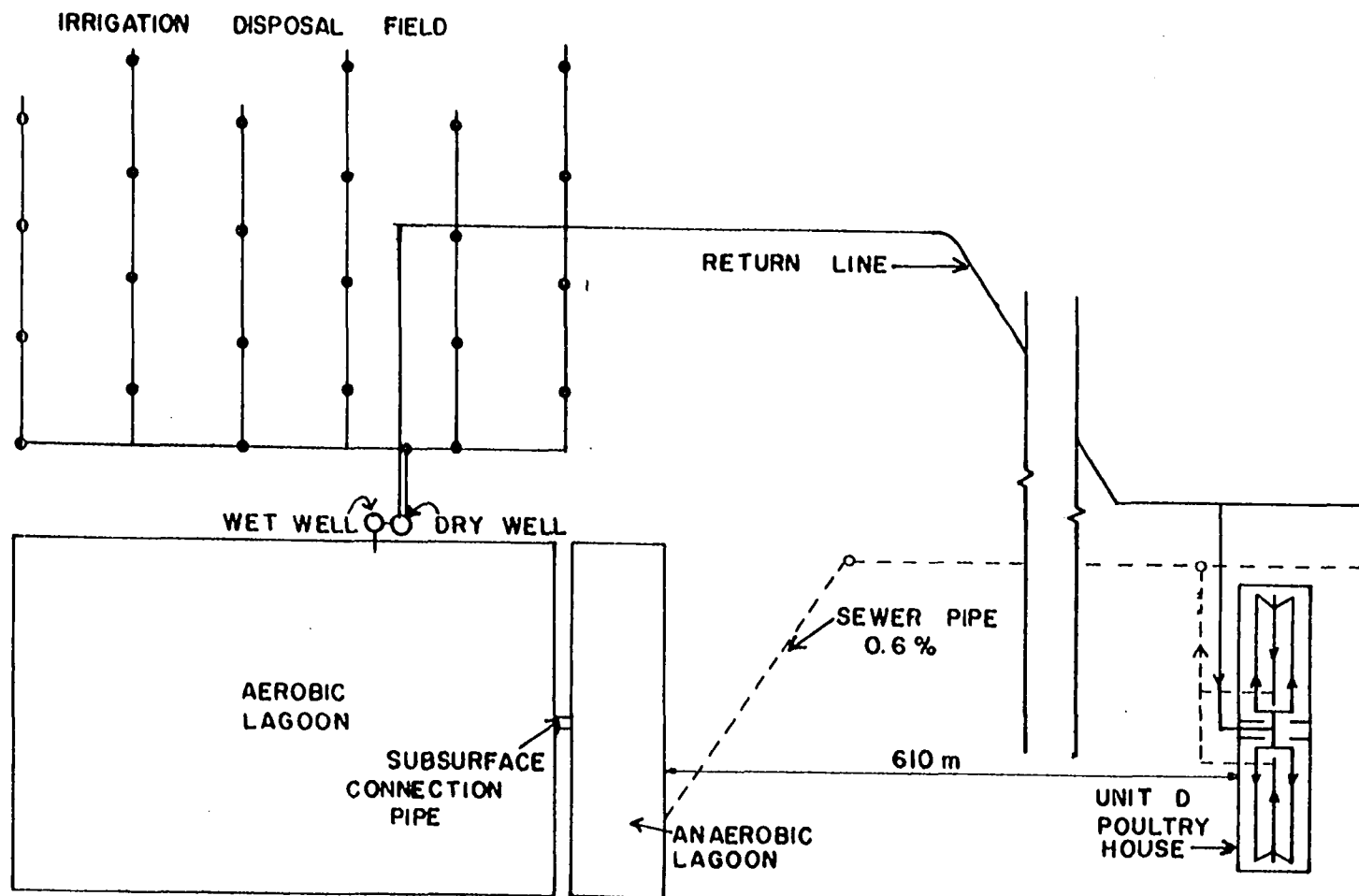


Figure 12. The waste treatment, recycling, and disposal system for Unit D

was judged necessary. The flushing-gutter manure-handling system to be described is not necessarily an optimum design but rather the best possible with the physical restraints of the building.

To accommodate the in-house recycling system in Unit D, flush trays were installed below the outer stairsteps of cages, and the center pit was reformed (Figure 13). The flushing trays were fabricated (in sections) from 0.9 mm metal sheets 305 cm long and 54 cm wide, which were epoxy-coated to prevent corrosion (Figure 14). A 2.5 cm vertical lap was included to prevent meandering, add structural rigidity and aid in final assembly. Three sections were riveted together to form a 162 cm wide tray and then 8 sections were riveted end-to-end to form a 24 m tray. The flush trays are supported by steel angle frames with adjustable pipe legs which allow the tray to be adjusted vertically, thereby changing its slope, (Figure 15). The trays were installed with a 0.63% slope.

At the end of each tray is a flush-water-collection gutter, 36 cm wide and 162 cm long (Figure 13) which was formed at the end of the existing pit. The collection gutters are sloped toward the center pit to move the flush water through the cross channels to the center pit.

The central pit, 162 cm wide and 24 m long, was reformed to provide an area for in-house recycling-water storage. The pit was reformed with three different slopes (Figure 16). The first 18 m section, where the cross channel enters, has a slope of 0.42% and is cleaned by the flush water from the trays. Meandering was prevented in this section by anchoring an angle iron to the floor

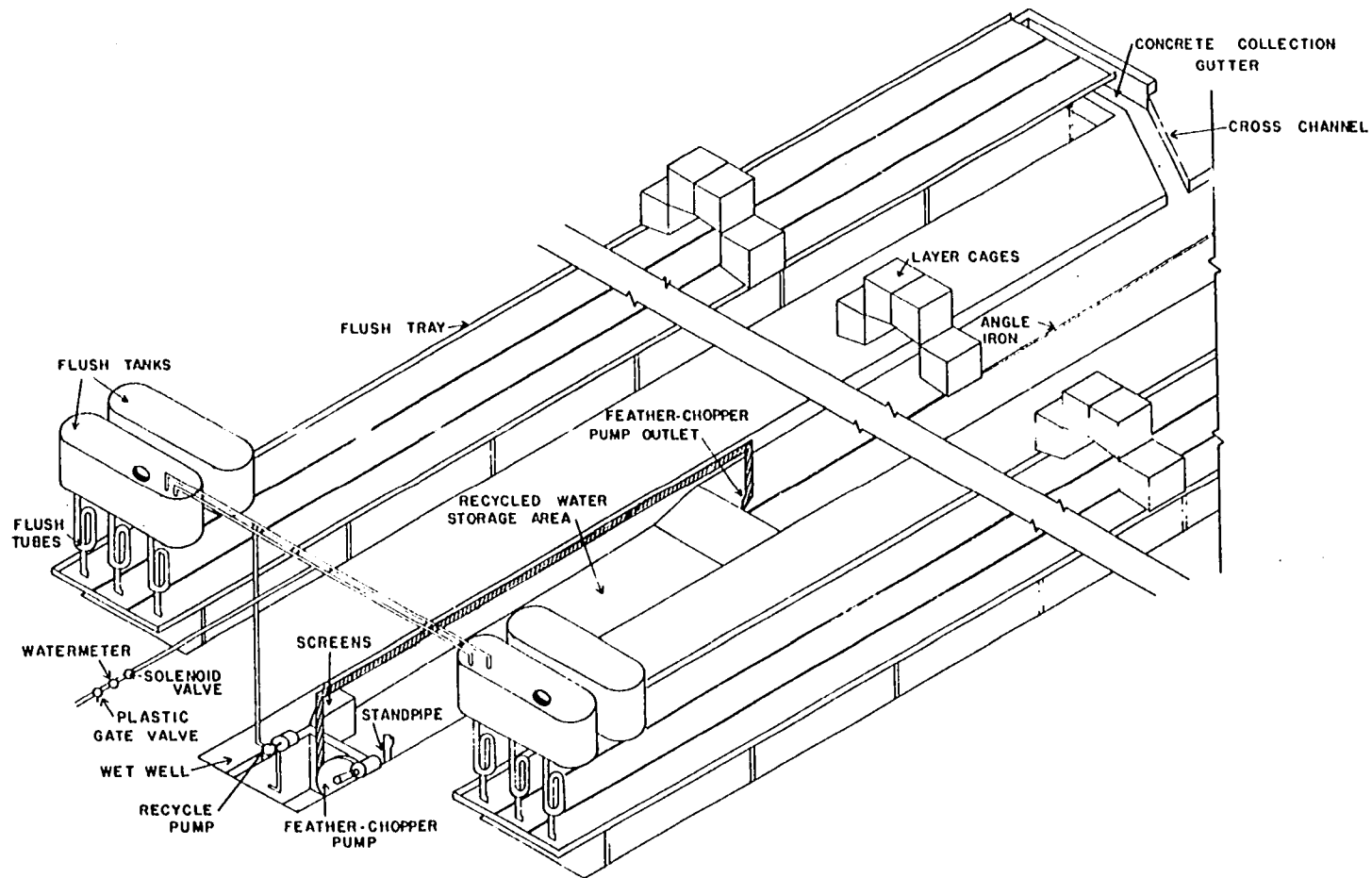


Figure 13. The flushing-gutter manure-handling system in Unit D

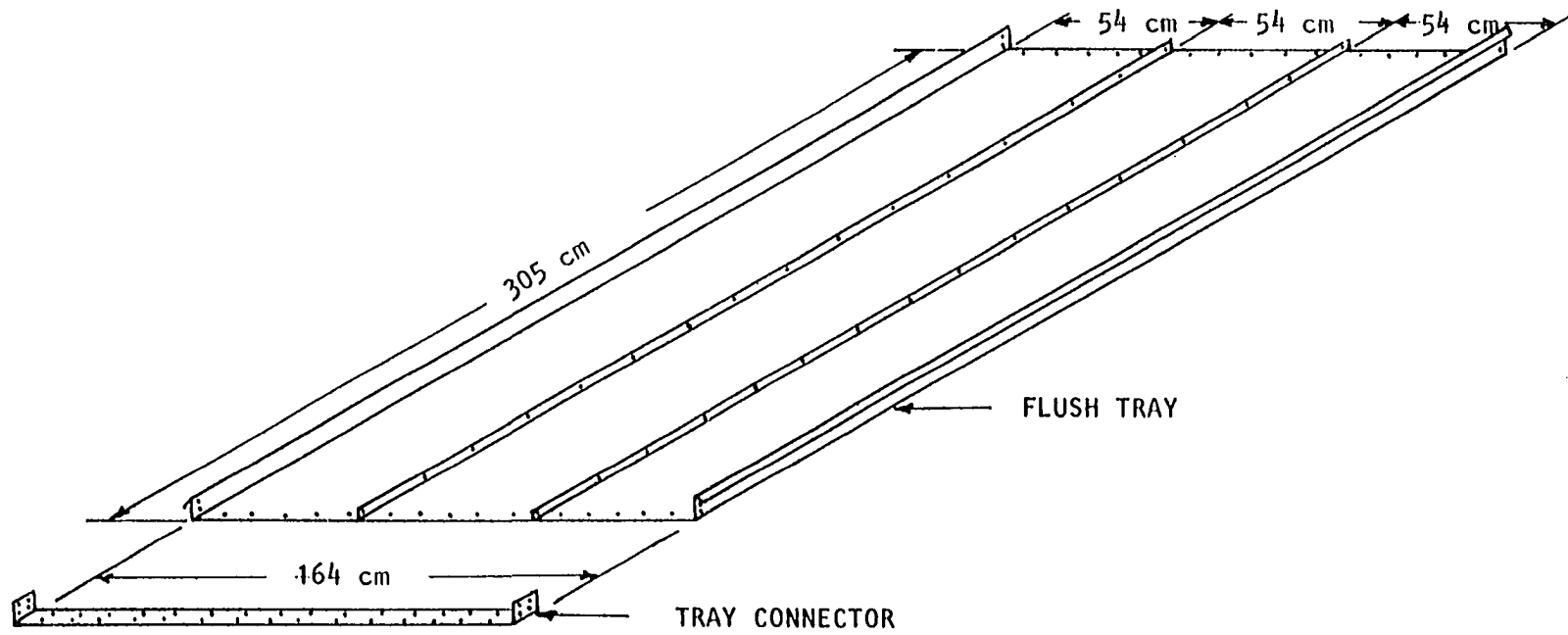


Figure 14. Isometric of fabricated flushing tray section, with tray connector

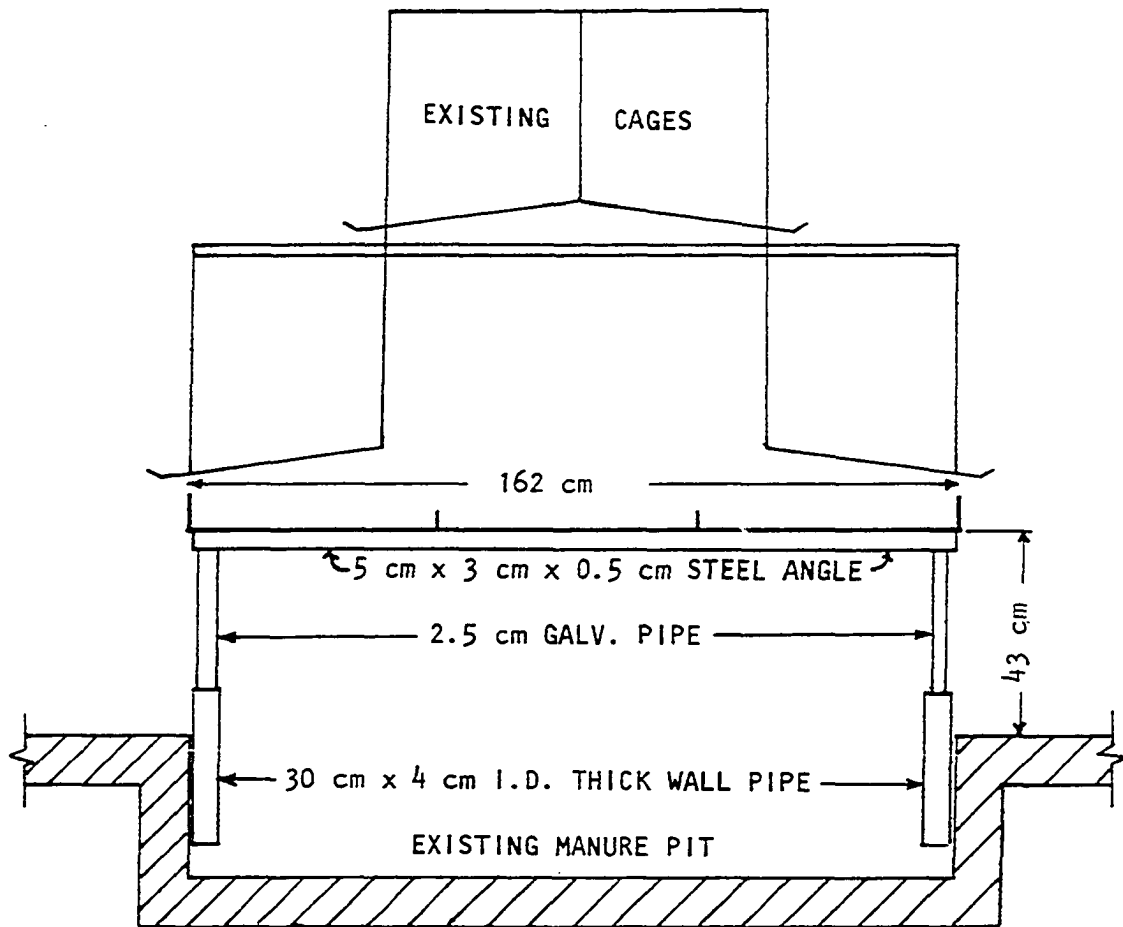


Figure 15. End view of existing cages, flushing tray and existing manure pit

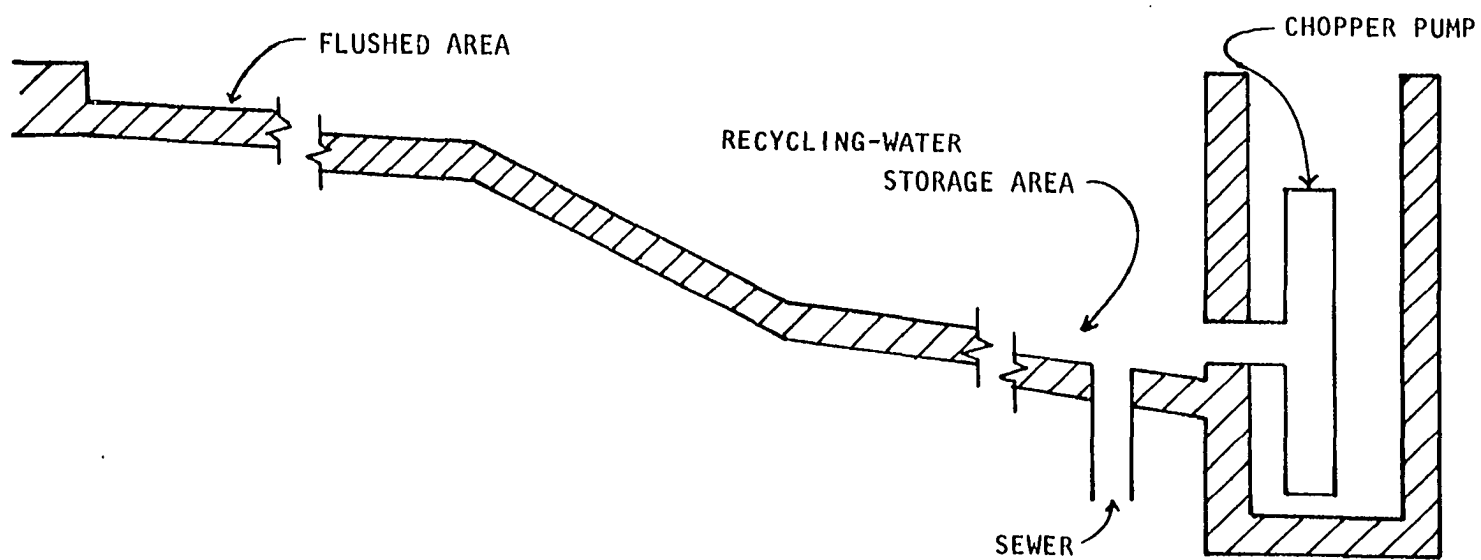


Figure 16. The reformed center pit in Unit D

in the center of the pit. The next 60 cm section of the pit drops 46 cm, 77% slope, to provide a 3400 l area for storage of the in-house recycling water in the final 5.5 m section. The final section was formed with a 1.85% slope to aid in cleaning the manure which settles in the storage area during in-house recycling. A stand-pipe was installed in the sewer inlet in the recycling-water-storage area to maintain the desired water level (Figure 13).

To accommodate the wet and dry wells required for in-house recycling, a 122 cm section of floor was removed at the end of the center adjacent to the flush tanks (Figure 13). The dry well was designed to accommodate a feather-chopper pump (Figure 17) (Van Ee, 1972). Grinding of the feathers and agitation of the manure in the recycled-water-storage area by the feather-chopper pump aids in cleaning and reduces the possibility of feathers plugging the sewer line. The wet well is separated from the center pit by a 3.2 mm screen.

Recycled water is pumped from the wet well to flush tanks with a flexible rubber impeller pump. The screen on entrance to the wet well was installed to prevent feathers from plugging the recycle pump. The pump used in this installation is a Jabsco No. 777 plastic-bodied unit powered by a 560 W electric motor. A cyclic timer and float switch were installed to control the recycle pump (Figure 18). The cyclic timer permits the number of daily tray flushings to be varied, while the float switch prevents the recycle pump from operating without sufficient water in the wet well.

Above each flush tray, two interconnected tanks were installed

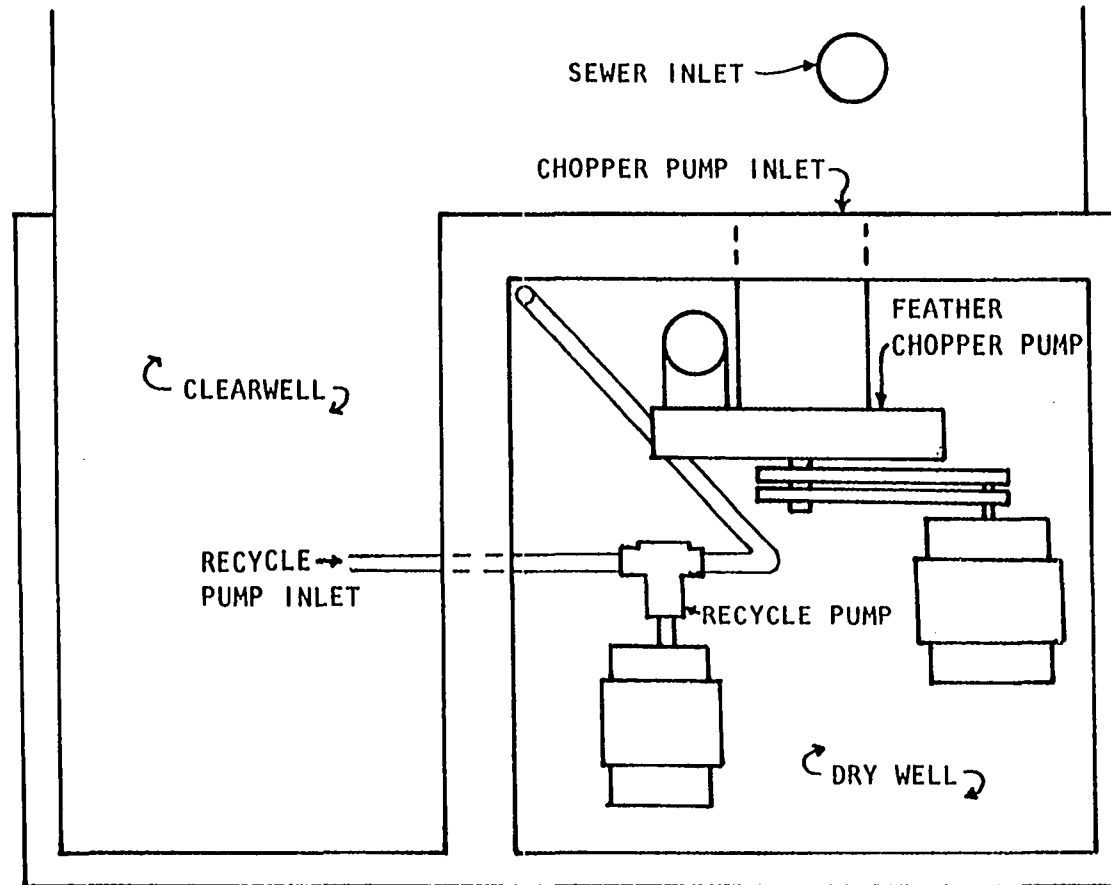


Figure 17. The clearwell and dry well at the end of the reshaped center pit in Unit D

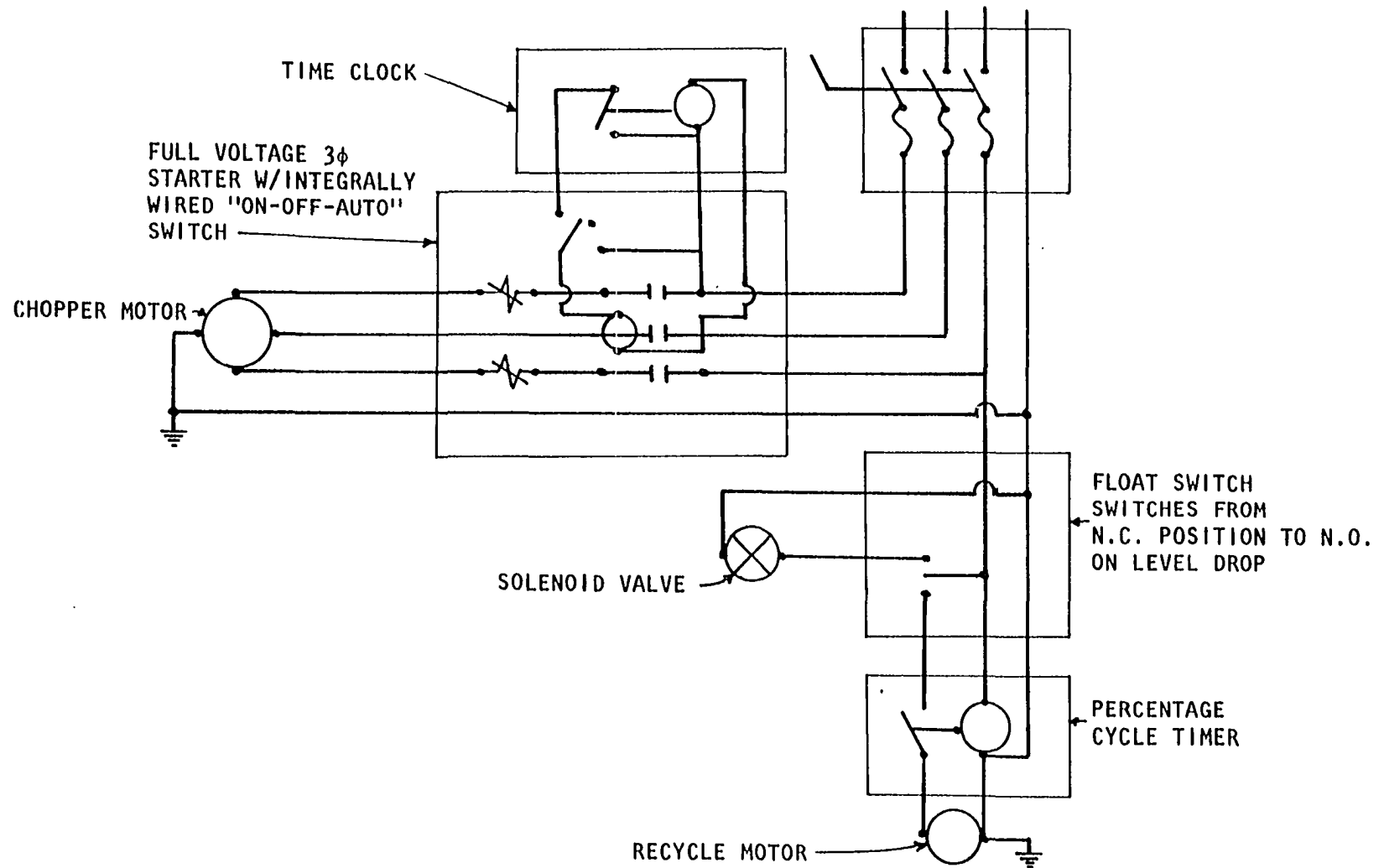


Figure 18. The electrical control diagram for the chopper pump and recycle pump

(Figure 13). Two 568ℓ livestock-watering tanks were interconnected by a 20 cm tube to provide sufficient water to clean the trays. The recycled water was flushed by dosing siphons installed in one of the tanks. (Figure 19). Three flush tubes, 7.6 cm PVC pipe, were installed under a common bell, 76 cm x 15 cm x 20 cm, which causes all three tubes to flush simultaneously.

The effluent from the recycling-water-storage area flows into a two-stage lagoon system. The first stage is an anaerobic lagoon connected by a subsurface pipe to an aerobic lagoon, the second stage of treatment. These lagoons also handle the wastes of other types of livestock located at the Animal Teaching Station. Effluent from the aerobic lagoon is returned to Unit D by a pump located near the lagoon (Figure 12). The excess effluent from the aerobic lagoon is irrigated on an adjacent sheep pasture with a solid-set irrigation system.

A 5.08 cm plastic line is used to return the treated lagoon effluent to Unit D. After entering Unit D, the treated water flows through a ball valve, then into 1.9 cm ABS pipe. This pipe runs to the ceiling of Unit D, where it tees and runs to both the east and west sides. To control the treated-water flow into either side, solenoid valves and plastic gate valves were installed in both lines (Figure 13). The gate valve provides a means of complete treated-water shutoff, which is useful when draining the recycling water out of the building. The solenoid valve responds to provide treated water to the in-house system when there is insufficient water to operate the recycling pump (Figure 18).

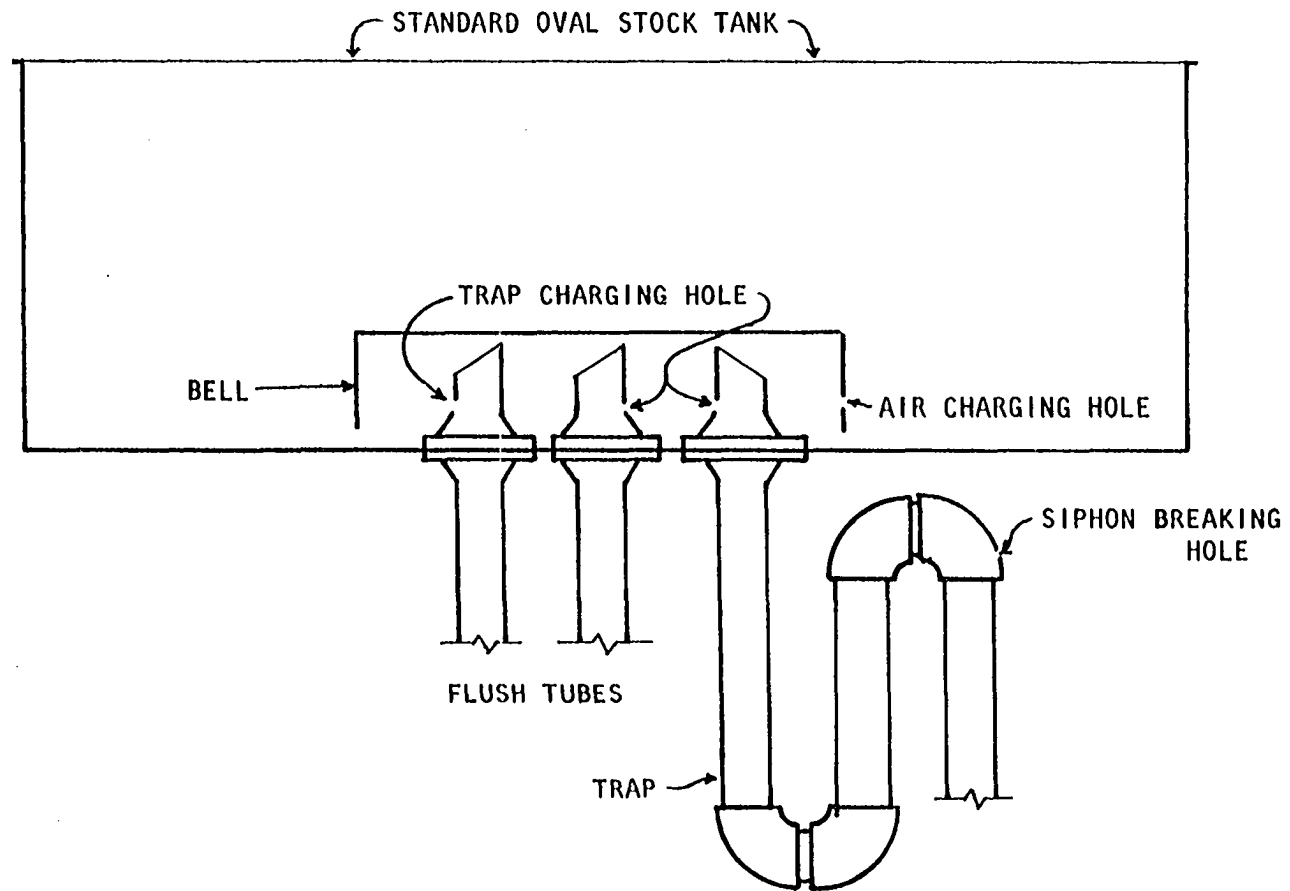


Figure 19. Triple dosing siphons which provide water for flushing the trays

Normal Operating Procedure

Since completion of the installation in 1973, the manure-handling system's management has included biweekly cleaning of the recycled water-storage area, monthly cleaning of the flush trays, and occasional cleaning of the flush tanks. These management methods were adopted by the personnel working in Unit D as the best compromise between labor input and proper system operation. Normal operating procedure includes allowing the continuous-flow, bird-watering system to flow into the recycled-water system at the rate of 9690 L/day.

During the winter, the ventilation inlet slots (Figure 11) are closed and partially sealed with tape to reduce the infiltration of cold air. The inlet under the overhang of the roof is also covered with plywood to help reduce infiltration. These operating procedures are necessary due to the low bird density in the building. The small exhaust fans located on the end of each wing are operated continuously during the winter, with the supplemental heaters maintaining the temperature inside the building at approximately 16 °C. In order to evaluate this system in normal operation a minimum amount of changes were made in the normal operating procedures.

METHODS OF ANALYSIS

Atmospheric-Ammonia Concentrations

Atmospheric ammonia concentrations were measured by collecting it in dilute sulfuric acid as ammonia sulfate and then Nesslerizing the sample. Air was drawn through a midget impinger containing 20 ml of .02 N sulfuric acid at a rate of 1.0 l/min for 15 min, (Figure 20). Distilled water was then added to the sulfuric acid to bring the sample volume to 25 ml . One ml of Nessler Reagent (Hach Chemical Company) was added which produced a yellow to brown color, dependent on the concentration of ammonia in the sample. The color intensity was measured by a B & L Spectronic 20 at a wave length of 425 nm. A calibration curve developed by the Hach Chemical Company was used to determine the concentration of ammonia in the sample (Figure 21). The atmospheric-ammonia concentration was then calculated knowing the concentration of ammonia in the sample, volume of the sample, air sampling rate and the air-sampling time. This procedure for sampling atmospheric-ammonia concentrations has been reported and used by several researchers, including Jacobs (1967), Leithe (1970), Ludington et al. (1969), Miner and Hazen (1969), and Morgan et al. (1967). Collection of atmospheric ammonia in dilute sulfuric acid is very efficient, over 99% for sampling times up to 15 min (Morgan et al., 1967, Okita and Kanamori, 1971). This allows the use of only one impinger, which simplifies sampling.

The rate of air flow through the midget impinger was controlled by a limited-flow orifice. The phenomenon of limited flow through

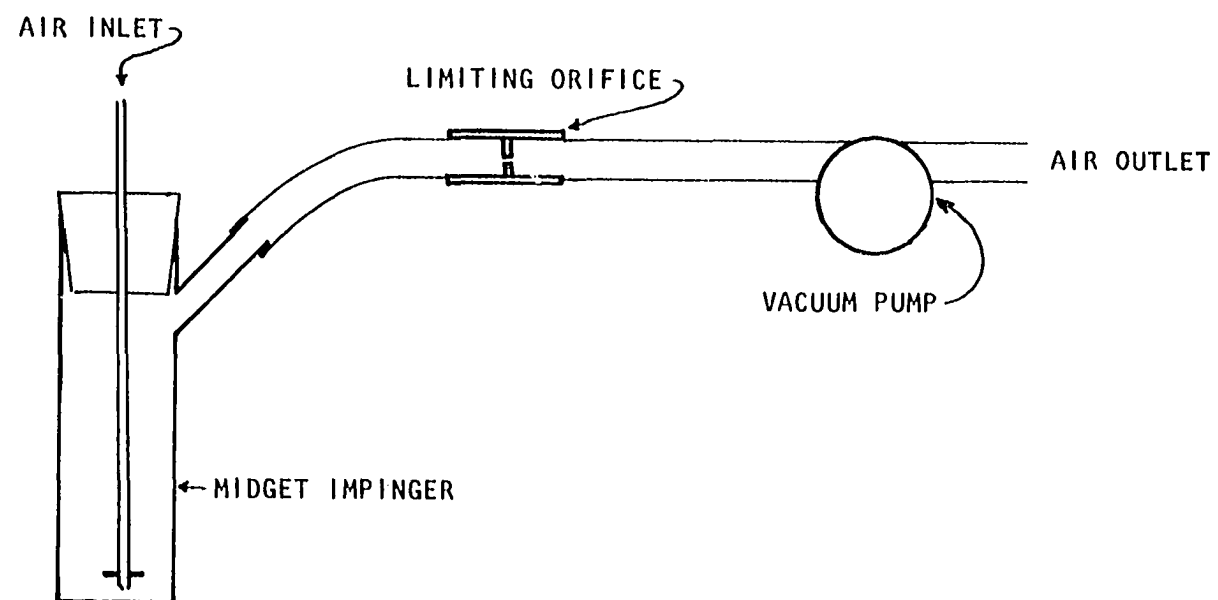


Figure 20. Apparatus used for sampling atmospheric ammonia

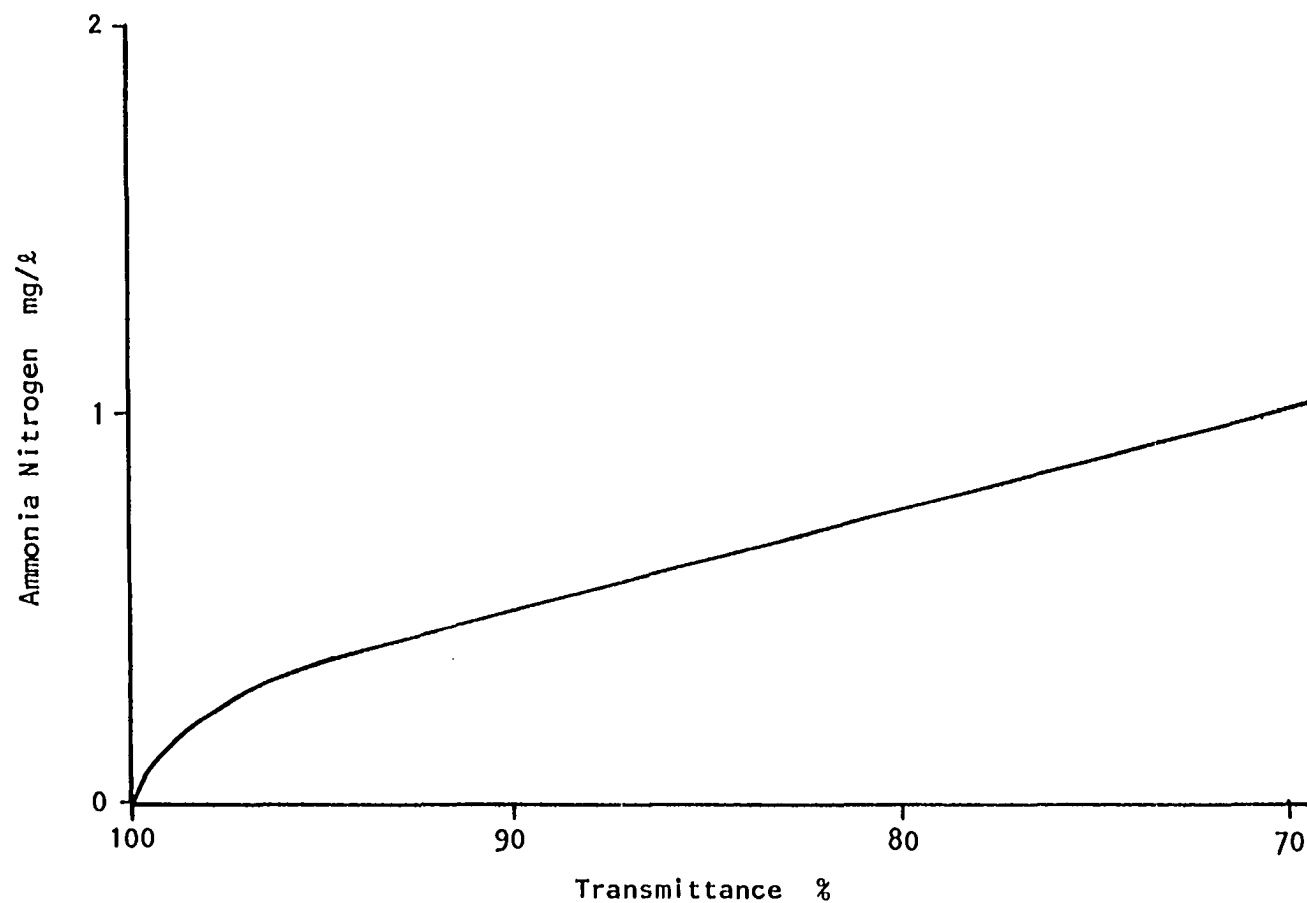


Figure 21. The relationship between percent transmittance and ammonia-nitrogen concentrations in Nesslerized samples of dilute sulfuric acid (Adapted from Hach Chemical Company, Ames, Iowa)

a small converging orifice results when the velocity of gas at the throat of the orifice becomes sonic, Mach 1. No further increase in the velocity at the throat can occur without a change in the configuration of the orifice (Van Wylen, 1962). As the pressure drop across an orifice increases, the flow rate through the orifice increases until the gas velocity at the throat becomes sonic. Any further increase in the pressure drop across the orifice will not cause any increase in the flow rate (Brenchley, 1972). This allows a constant flow rate to be maintained with a variable vacuum source as long as sufficient vacuum is developed to maintain sonic velocity in the orifice throat. Figure 22 is a typical graph of flow rate versus pressure drop across an orifice. When the pressure drop across the orifice is greater than or equal to 0.6-0.5 times the pressure upstream from the orifice, sonic velocity is developed in the orifice throat. The pressure drop required is dependent on the configuration of the orifice.

Limited-flow orifices can be purchased commercially, or other manufactured items can be calibrated, such as hypodermic needles, watch jewels, or glass capillaries (Brenchley, 1972; Huygen, 1970; Lodge et al., 1966). Before the arrival of the commercial orifice used during the majority of the sampling described, hypodermic needles were calibrated for sampling. The needles were calibrated with a flow meter, accuracy $\pm 1\%$ of reading, capable of measuring low flow rates of less than 2 $\mu\text{L}/\text{min}$. Table 2 indicates the range of flow rate achievable with various gage needles. Also shown is the effect of adding 1 or 2 midjet impingers to the intake line of

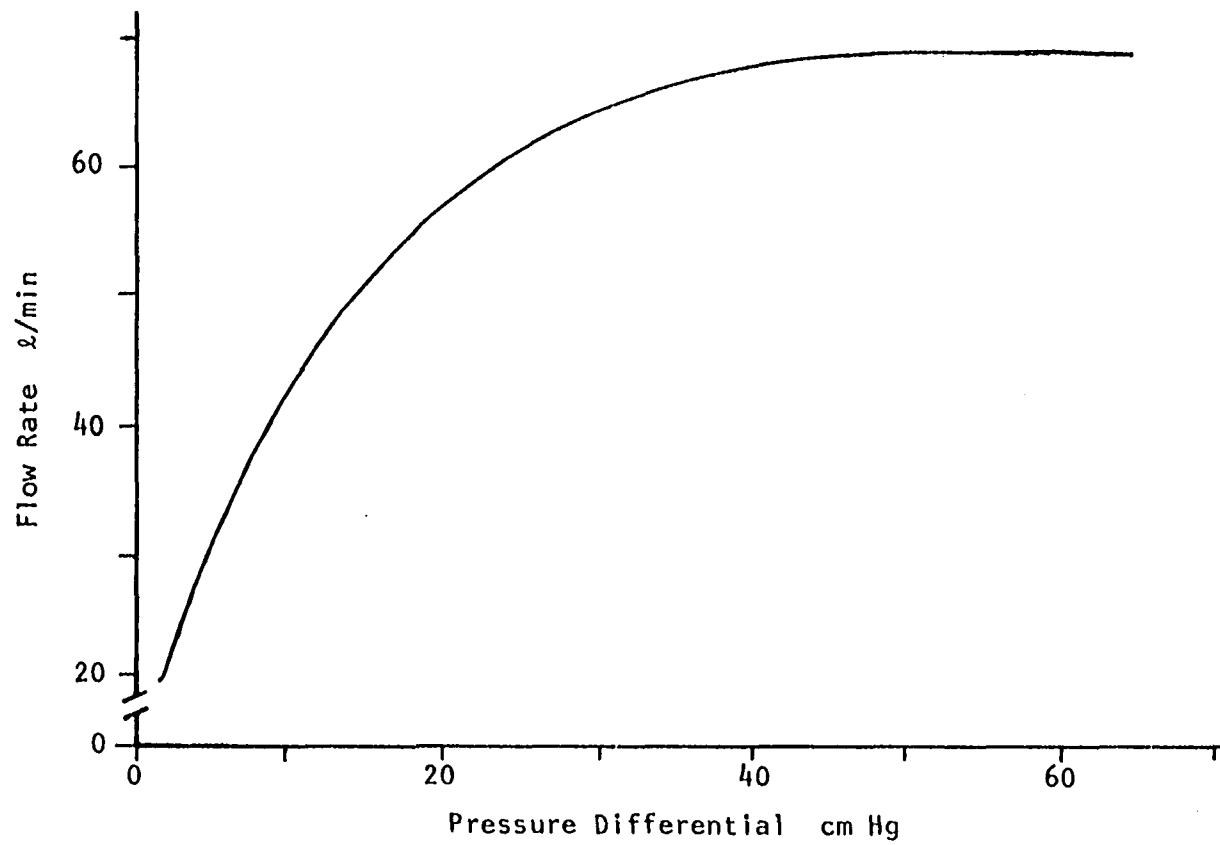


Figure 22. Flow rate versus the pressure differential across an orifice

Table 2. Flow rates^a through hypodermic needles used as limiting orifices

Needle gage	Needle length cm	Number of impingers in series with the needle		
		0	1	2
		Flow rate - ℓ/min		
20	5.1	1.81	1.81	1.80
21	3.8	1.40	1.40	1.40
22	3.8	0.86	0.86	0.86
23	3.8	0.56	0.56	0.56

^a Flow rates measured at 64 cm Hg.

the orifice. Tests run using 20 ml of distilled water in each impinger indicate that 1 or 2 midjet impingers have little effect on the flow through an orifice with a vacuum above 51 cm of mercury.

Calibrations done of five hypodermic needles of the same gage, made by one manufacturer, indicated that enough variation occurs to require individual calibration (Table 3).

Table 3. The variation in flow rates through hypodermic needles of 23 gage used as limiting orifices

Needle	Flow rate - ℓ/min	
1	0.561	
2	0.575	
3	0.518	Average = 0.547 ℓ/min
4	0.549	Standard deviation = 0.023 ℓ/min
5	0.532	

Since any change in the configuration of a limited-flow orifice will change the maximum flow rate, the commercial orifice used for sampling was recalibrated during testing. The dust and atmospheric ammonia found in the experiment unit altered the orifice configuration substantially. Before sampling, the maximum flow rate of the orifice was 1.031 ℓ/min and by the completion of sampling, the flow rate

was reduced to 0.660 ℓ /min.

The vacuum pump used for sampling was chosen with the capacity to provide a higher flow rate than required by the orifice. This was done to insure that the vacuum-pump capacity was not actually limiting the air-flow rate at vacuums above 51 cm of mercury. The vacuum pump used was a 124 W, lubricated, rotary-vane unit, capable of an air-flow rate of 2.83 ℓ /min at 64 cm of mercury.

Flush Water

The recycled flush water was routinely analyzed for Kjeldahl-N, ammonia-N, COD, total solids, and volatile solids content. The pH and conductivity were also routinely measured on fresh samples. The general procedure outlined in Standard Methods (1971) was used for the routine analysis of all measured water-quality parameters. A Fisher pH meter, Model No. H2, calibrated using a standard buffer solution of pH 7, was used for pH determinations. Conductivity measurements were made with a Yellow Springs Conductivity Bridge Model No. 31. Temperature measurements were made in the recycled water storage area while fresh samples were being obtained for the above analysis.

Temperature and Humidity

A sling psychrometer was used to make air temperature and humidity measurements inside Unit D. The air wet and dry bulb temperatures were measured directly while the humidity was determined by calculation or read directly from a psychrometric chart. A strip chart hygrothermograph recorder was used to measure external temperature and humidity when the temperature was below 0 °C because the wet

bulb thermometer could not be used below this temperature. The measurements were made or charts read while the atmospheric ammonia samples were being made.

Ventilation Rate

Measurement of the ventilation rate of an enclosed poultry house can be reasonably approximated but accurate measurement is difficult. Since a relationship between atmospheric-ammonia concentrations and ventilation rate has been established in the literature, accurate measurements of the ventilation rate was not done for this research project. Accurate measurement of ventilation rates are hampered by changes in the air pressure at the inlets. Also, some methods of measurement may actually affect the ventilation rate.

An estimate of the ventilation rate was obtained by measuring the pressure drop across the fan and use of manufacturer's data. The fan units were manufactured by the American Coolair Corporation. However, in a conversation with a representative of the American Coolair Corporation's engineering department, it was learned that the fan blades were manufactured by the Torrin Corporation and that more reliable fan-performance curves could be obtained from them. Figure 23 shows the general shape of the fan-performance curves obtained. Static pressure drops measured on the fans at Unit D were converted to air-flow rates by use of fan-performance curves and then total ventilation rates were calculated for various combinations of fans (Table 4).

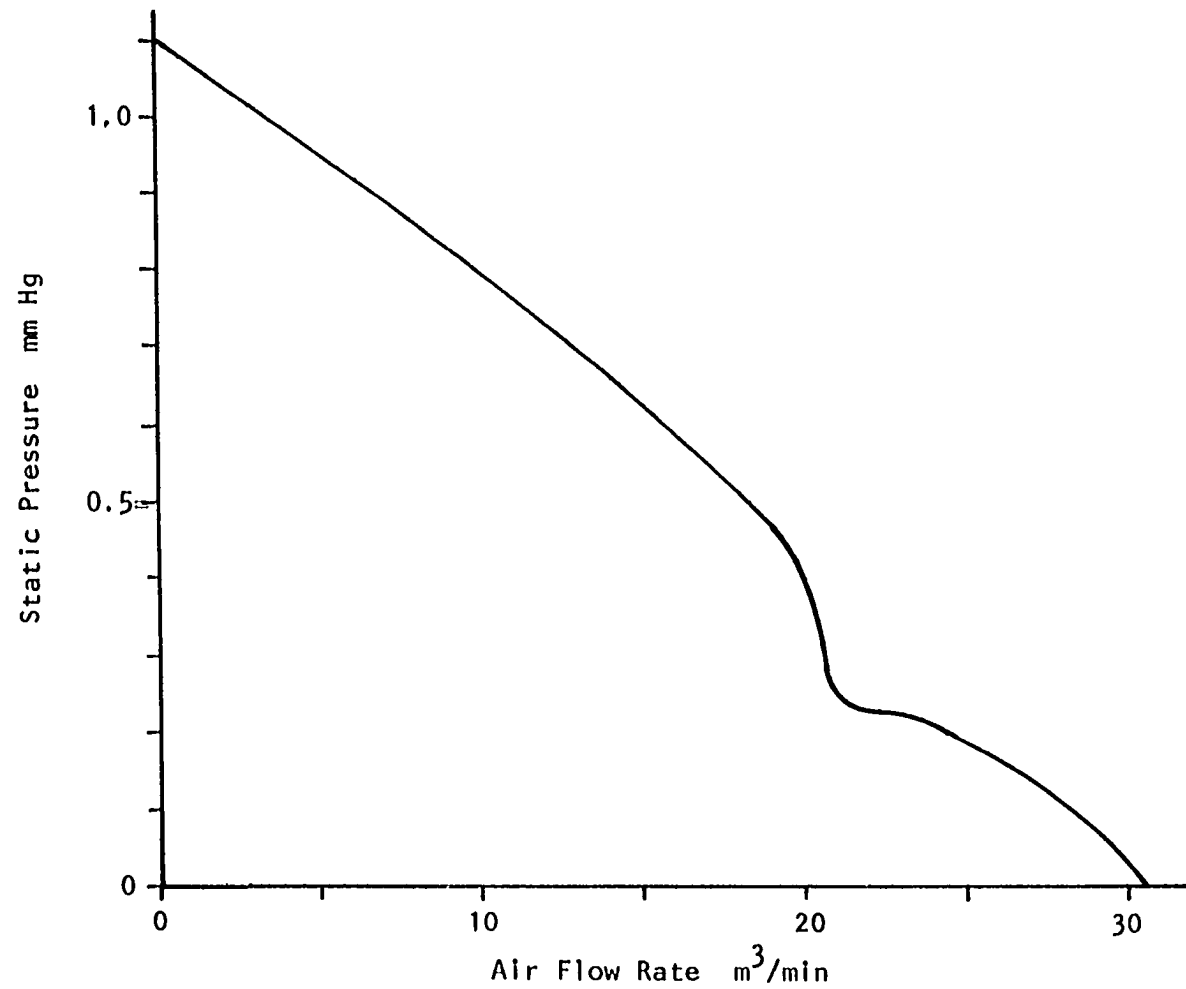


Figure 23. General shape of the fan-performance curves for the fans at Unit D (Adapted from Torrín Corporation, Torrington, Connecticut)

Table 4. Calculated ventilation rates for Unit D

Fans operating = x					
Fan	Fan 2		Fan 3		
1	Low	High	Low	High	Ventilation rate - m ³ /min
x .....	..	...	..	.....	28
x	x ..	...	..	.....	77
x	x ..	...	x ..	.....	125
x .....	..	x ..	..	x ..	175

EXPERIMENTAL PROCEDURE

To achieve the objectives of this research project, the experimental installation was closely monitored during the winter and spring of 1975. Daily sampling of the recycled water and atmospheric-ammonia concentrations was done between supervised pit cleanings.

Atmospheric-ammonia concentrations were measured at one location and at one height. One site was used so that variations in atmospheric-ammonia concentrations which may occur at various locations in the house would not interfere with the objective of determining the interaction between flush-water quality and atmospheric-ammonia concentrations. The variations in atmospheric-ammonia concentrations would not be predictable because of changes in infiltration due to the wind and thermal convection currents caused by the birds and the flush trays.

The use of one site to evaluate the atmospheric-ammonia concentration was tested and analyzed statistically. Samples were taken at various locations in Unit D consecutively. A statistical analysis of the data indicated that there were no consistent differences between the sampling location chosen and other locations in the building (Table 5).

To aid in the evaluation of the effect of recycled water quality on the internal environment, the continuous-flow, bird-watering system was modified to prevent its overflow water from entering the recycled water-storage area. This was accomplished by installing a 5.1 cm plastic-pipe collection system at the end of the waterer

Table 5. The effect of location on the measured atmospheric ammonia concentrations in Unit D

	<u>DF</u>	<u>SS</u>	<u>MS</u>	<u>F</u>
Day	18	13.89	0.77	0.48 N.S. ^a
Location	1	0.23	0.23	
Residual	<u>18</u>	<u>8.59</u>	<u>0.48</u>	
Total	39	22.71	0.58	

^aNot significant.

troughs. An earlier attempt to use a 1.9 cm rubber hose failed due to plugging problems caused by iron bacteria slime. The collection systems at the end of the cages above the trays drained directly into the side pits, which drain into the sewer system, while the water from the collection system on the center rows of cages was pumped into a side pit. Monitoring was done with and without the overflow water entering the recycled, water-storage area.

RESULTS

Analysis

The data in Appendix A were analyzed with the computerized statistical analysis program. The data were separated in two treatments for a portion of the analysis. Treatment 1 and Treatment 2 data were taken without and with the waterer overflow entering the recycled water-storage area respectively.

The rate of waterer overflow entering the recycled water-storage area varied daily. Table 6 shows the differences in waterer overflow

Table 6. Waterer-overflow rates measured in Unit D

<u>Day</u>	<u>Individual waterers</u>		<u>Total overflow</u>
	<u>Mean</u>	<u>Standard deviation</u>	
1	561 ℓ/min	122 ℓ/min	6730 ℓ/min
2	767	251	9200

rate measured on 2 days. Changes in the waterer overflow rate were affected by iron-bacteria-slime buildup in the control valves and the daily adjustment of the valves by the building operator. Because of the continual variation in the rate of waterer overflow, only the general effect of waterer overflow entering the recycled water area, treatment 2, is considered in the following analysis.

Flush Water Quality

Nitrogen concentrations

The Kjeldahl nitrogen (TKN) analysis procedure measures the concentration of ammonia and organic nitrogen in the flush water

but does not measure nitrite and nitrate nitrogen. Organic nitrogen found in poultry manure may undergo decomposition and form ammonia nitrogen ($\text{NH}_3\text{-N}$) during storage. TKN analyses were performed to determine if decomposition were occurring and thereby increasing the $\text{NH}_3\text{-N}$ content of the flush water.

TKN concentrations in the flush water increased linearly with time during treatment 1, no overflow, and decreased slightly during treatment 2, with overflow (Table 7, Figure 24). The slope and

Table 7. The effect of time on Kjeldahl-nitrogen concentrations in the flush water

<u>Treatment</u>		<u>b value</u>	<u>t-test</u> <u>$H_o : b = 0$</u>	<u>Overall r</u>
1	Intercept	110.41	7.61**	0.98
	Slope	7.26	24.51**	
2	Intercept	87.32	14.40**	0.53
	Slope	-0.41	2.91**	
<u>Slope comparison</u>		<u>Intercept comparison</u>		
$H_o : \text{Slope 1} = \text{Slope 2}$		$H_o : \text{Intercept 1} = \text{Intercept 2}$		
t-test = 23.42**		t-test = 1.47 N.S. ^a		

^aNot significant.

** 1% level of significance.

intercept comparisons of the two treatments (Table 7) show that while the slopes of the two treatment lines are significantly different, their intercepts are not. Because flush water was recycled from a lagoon, the initial concentrations of TKN in the flush water were the same for both treatments.

The TKN concentration in the flush water increased linearly during treatment 1 as a result of the constant rate of manure addition

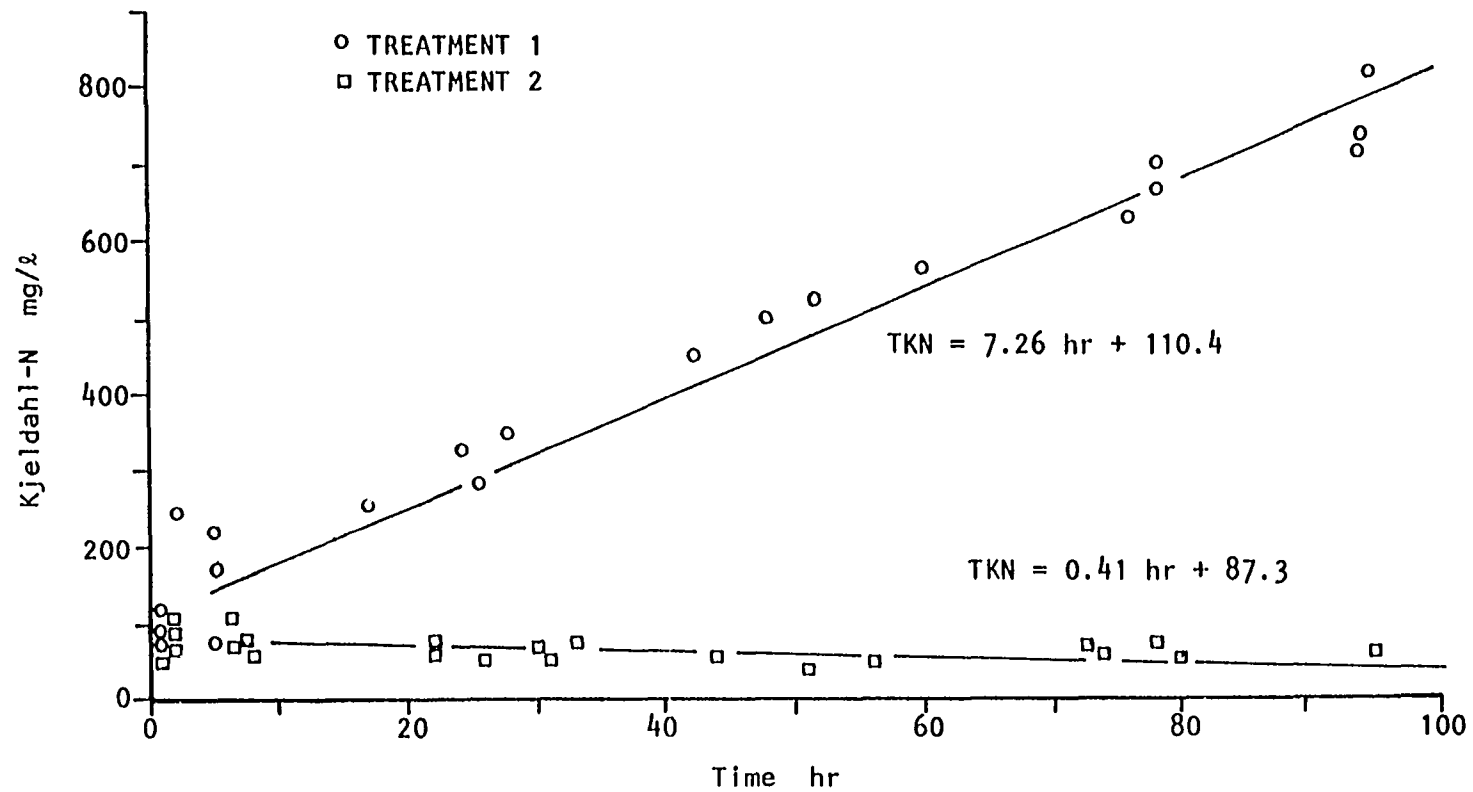


Figure 24. Linear regression of the effect of time on Kjeldahl-nitrogen concentrations in the flush water

by the birds. The linear increase also indicates that there was little, if any, decomposition of the organic nitrogen and uric acid while the flush water was being recycled in the building.

The lack of detectable decomposition is further substantiated by the linear relationship between TKN and $\text{NH}_3\text{-N}$ concentrations in the flush water (Table 8, Figure 25). Statistical analysis

Table 8. Ammonia-nitrogen versus Kjeldahl-nitrogen concentrations in the flush water

	<u>b value</u>	<u>t-test</u> <u>$H_0: b = 0$</u>	<u>Overall r</u>
Intercept	3.43	0.75 N.S. ^a	0.99
Slope	0.77	53.21**	

^aNot significant.

** 1% level of significance.

of the values for the slope and intercept of the relationship (Table 8) showed that the slope was significantly greater than zero, while the intercept was not significantly different from zero. Decomposition of organic nitrogen or uric acid during storage would have caused the $\text{NH}_3\text{-N}$ concentrations to increase in relationship to TKN concentrations.

In treatment 2, TKN concentrations in the flush water indicated that nitrogen addition from the manure was offset by dilution from the waterer overflow. The negative slope of the linear regression of TKN versus time for treatment 2 occurred due to the initial TKN concentration in the recycle water in the lagoon being higher than the equilibrium concentration in the building. TKN concentration in the recycle water in the lagoon being higher than the equilibrium

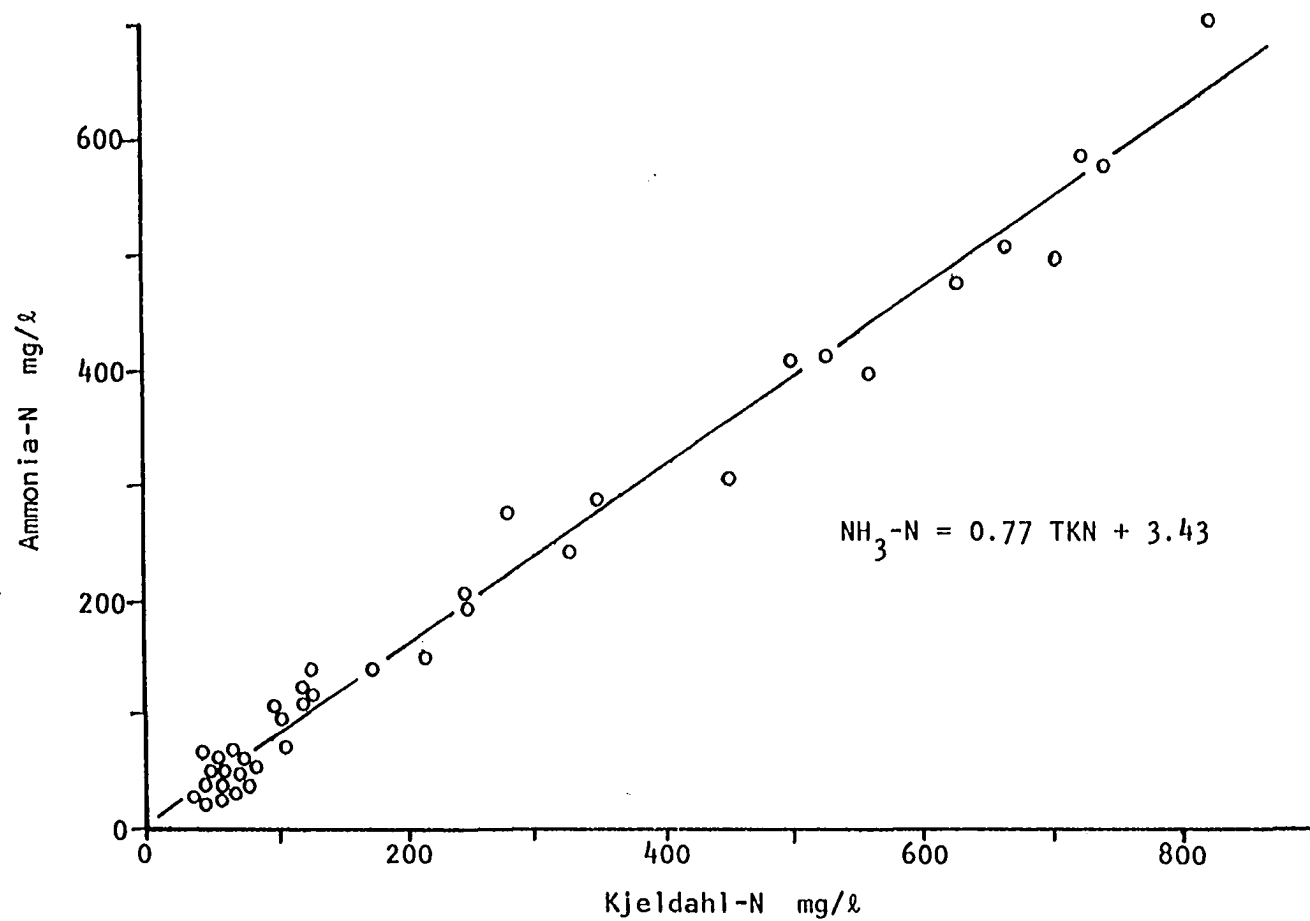


Figure 25. Linear regression of the relationship between ammonia-nitrogen and Kjeldahl-nitrogen concentrations in the flush water

concentration in the building. TKN concentrations in the lagoon increased during the winter after the water cooled and bacterial decomposition slowed and the ice cover reduced the rate of ammonia desorption (Figure 26). The average concentration of TKN in the flush water was 65 mg/l, at time > 0, while the average initial concentration was 109 mg/l.

As one would expect, because of the correlation between $\text{NH}_3\text{-N}$ and TKN concentrations in the flush water, $\text{NH}_3\text{-N}$ concentrations varied with time. $\text{NH}_3\text{-N}$ concentrations increased with time during treatment 1 and decreased during treatment 2 (Table 9, Figure 27).

Table 9. The effect of time on ammonia-nitrogen concentrations in the flush water

<u>Treatment</u>		<u>b value</u>	<u>t-test</u> <u>$H_o : b = 0$</u>	<u>Overall r</u>
1	Intercept	89.50	7.17**	0.98
	Slope	5.55	21.80**	
2	Intercept	75.17	9.08**	0.47
	Slope	-0.48	2.53*	
<u>Slope comparison</u>		<u>Intercept comparison</u>		
H_o : Slope 1 = Slope 2		H_o : Intercept 1 = Intercept 2		
t-test = 19.20**		t-test = 0.96 N.S. ^a		

^aNot significant.

** 1% level of significance.

* 5% level of significance.

The slopes of the two treatment lines are significantly different; however, the intercepts are not significantly different (Table 9).

The greater negative slope of the linear regression of $\text{NH}_3\text{-N}$ versus time for treatment 2 is less significantly different than zero than

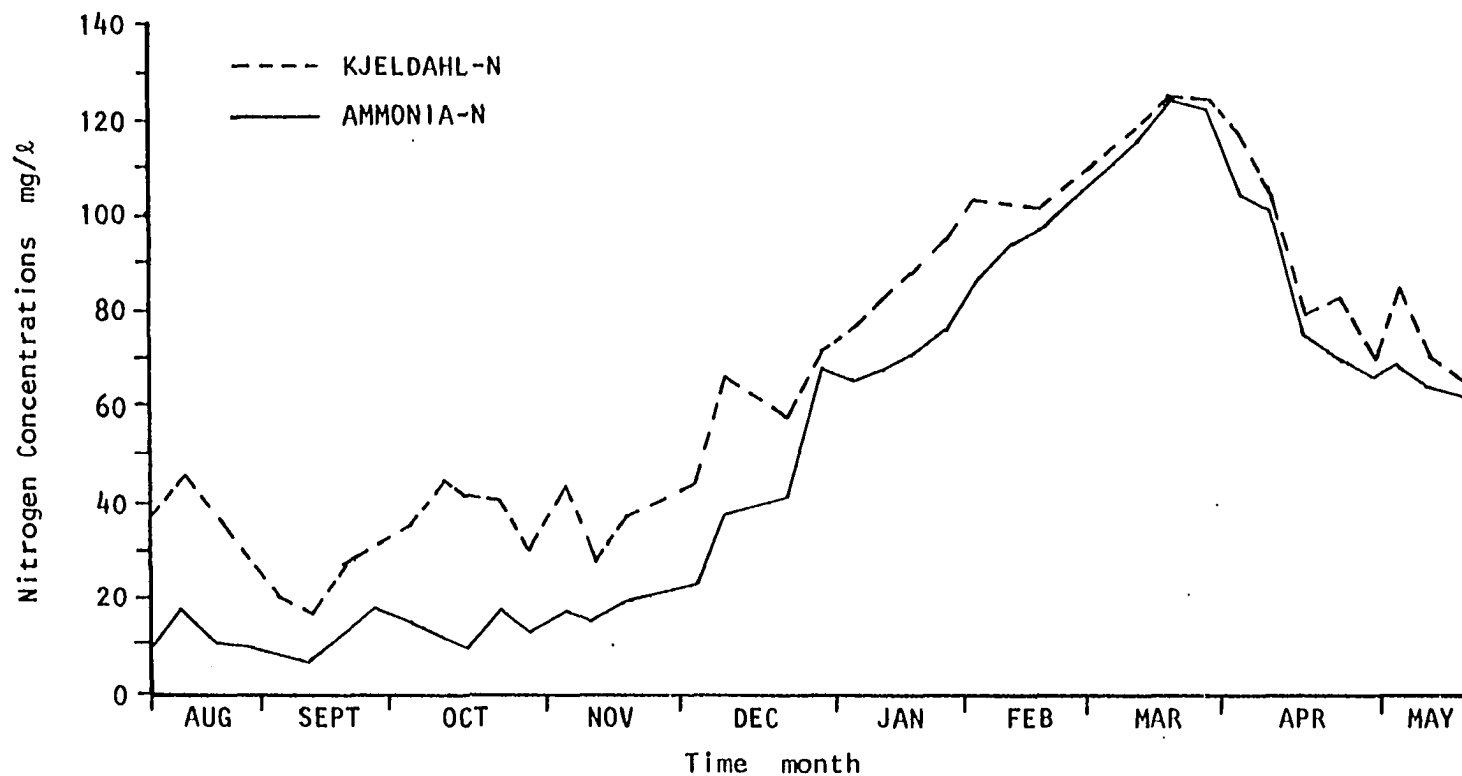


Figure 26. Monthly changes in ammonia-nitrogen and Kjeldahl-nitrogen concentrations in the aerobic lagoon at Unit D

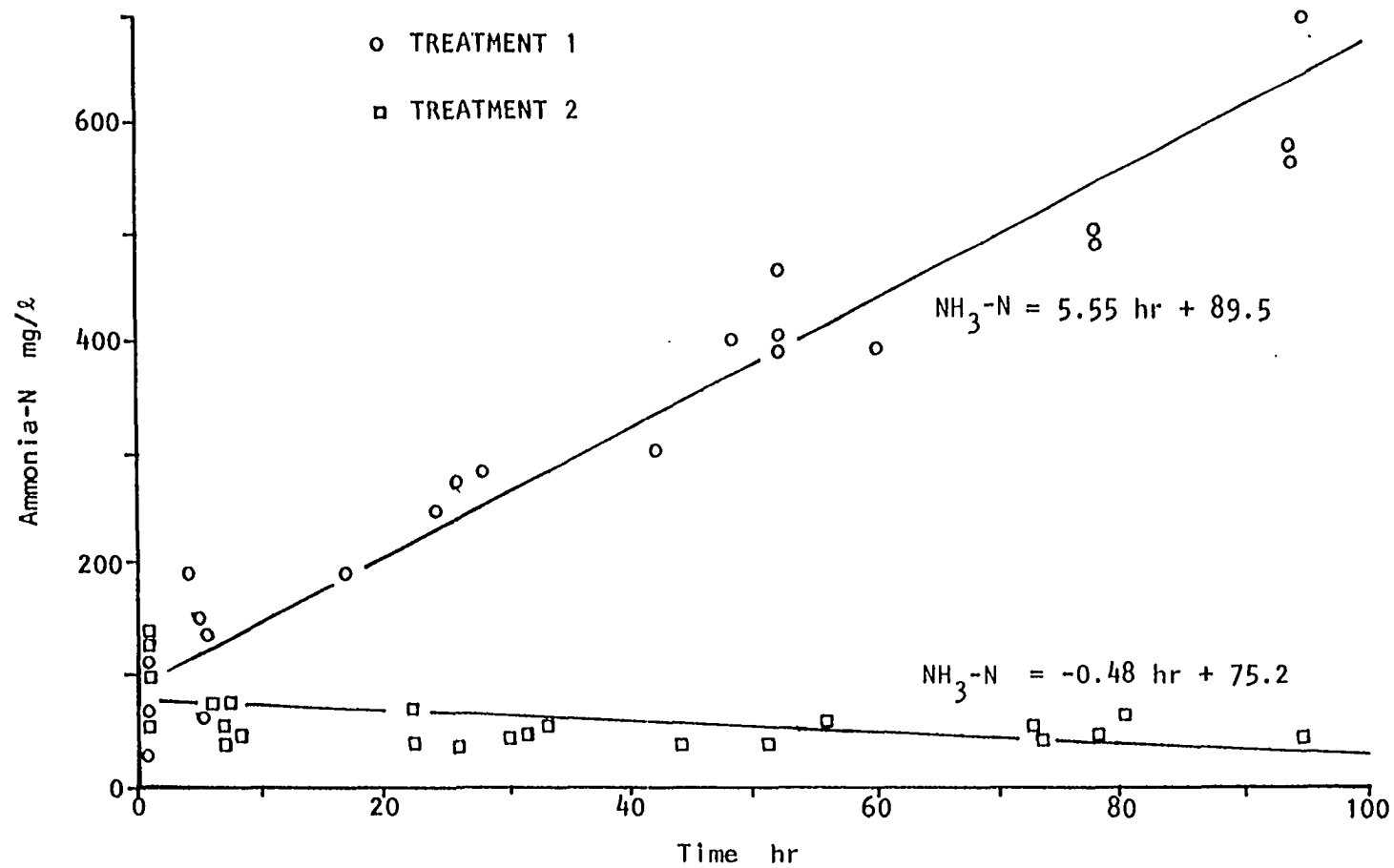


Figure 27. Linear regression of the effect of time on ammonia-nitrogen concentrations in the flush water

the slope of the TKN data for treatment 2. This is a result of higher initial values of $\text{NH}_3\text{-N}$, 112 mg/l, and lower average values, at time > 0 , 46 mg/l than the TKN initial and average values. Figure 26 shows the changes in $\text{NH}_3\text{-N}$ concentrations in a lagoon during winter conditions.

Solids concentrations

The total solids (TS) analysis measures the concentration of suspended and dissolved matter in the flush water. Solids in the flush water can cause difficulty with flush-water pumping and pump maintenance.

The TS concentration in the flush water increased linearly with time during treatment 1, no overflow, and did not increase significantly during treatment 2, with overflow, (Table 10, Figure 28).

Table 10. The effect of time on total-solids concentrations in the flush water

<u>Treatment</u>		<u>b value</u>	<u>t-test</u> <u>$H_o : b = 0$</u>	<u>Overall r</u>
1	Intercept	1385.17	20.40**	0.98
	Slope	34.80	21.90**	
2	Intercept	1534.51	47.55**	0.28
	Slope	1.01	1.34 N.S. ^a	
<u>Slope comparison</u>		<u>Intercept comparison</u>		
H_o : Slope 1 = Slope 2		H_o : Intercept 1 = Intercept 2		
t-test = 19.22**		t-test = 2.11 N.S. ^a		

^aNot significant.

** 1% level of significance.

The slopes of the two treatment lines are significantly different, but their intercepts are not significantly different. TS concentrations

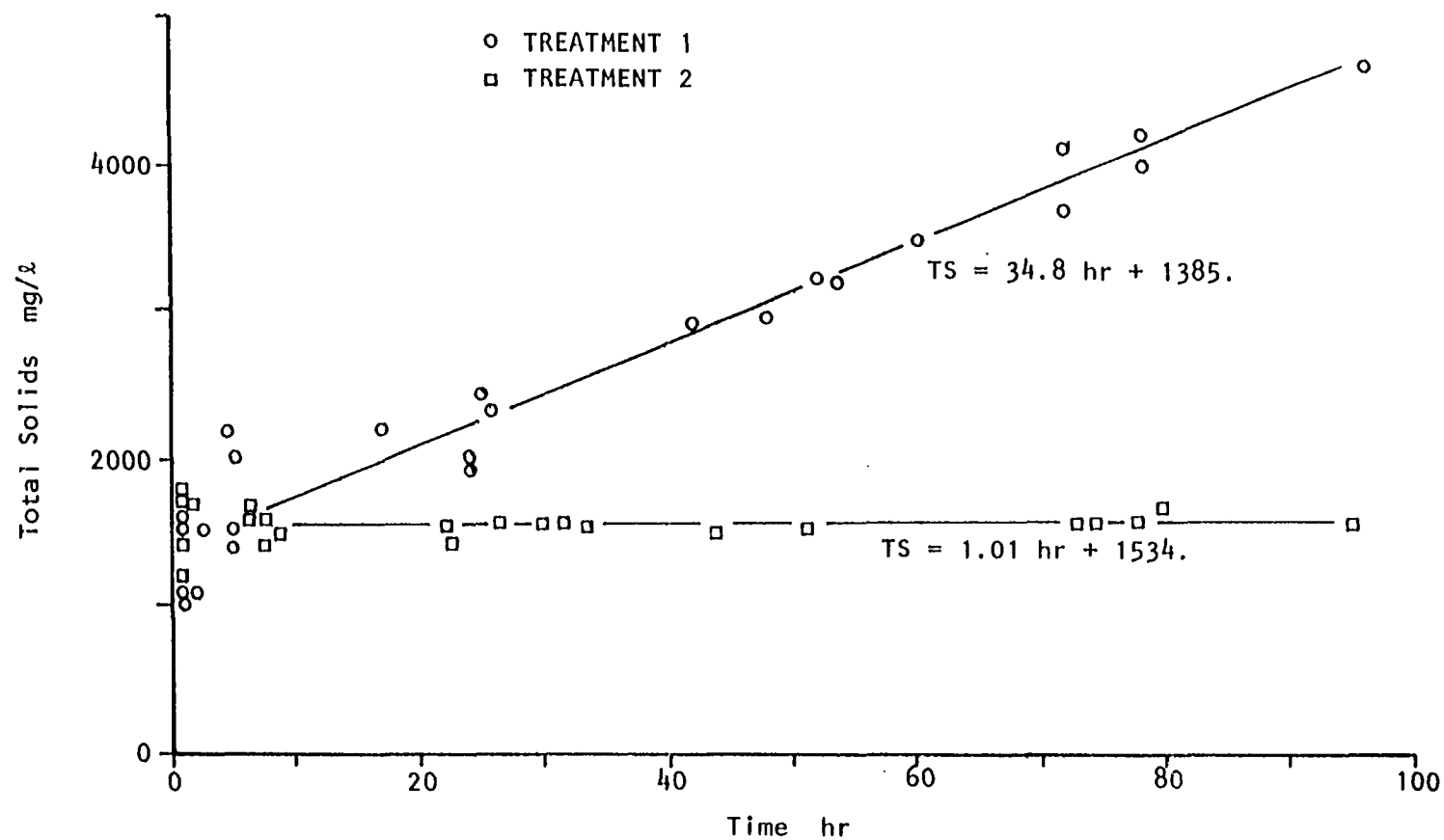


Figure 28. Linear regression of the effect of time on total-solids concentrations in the flush water

were not zero initially because there were some solids in the recycled flush water from the aerobic-lagoon.

The slope of the treatment 1 line was significantly different than zero because some of the manure that is flushed from the trays remained suspended and dissolved in the flush water. During treatment 2, the slope of the regression line was not significantly different from zero because the suspended and dissolved solids added by the flushed manure were being continuously removed in the overflow water.

The volatile-solids (VS) analysis performed on the suspended and dissolved solids matter in the flush water relates to the concentration of organic matter in the flush water. During treatment 1, the VS concentration in the flush water increased linearly with time; but, during treatment 2, it did not increase significantly (Table 11, Figure 29). Again there was no significant difference

Table 11. The effect of time on volatile-solids concentrations in the flush water

<u>Treatment</u>		<u>b value</u>	<u>t-test</u> <u>$H_o: b = 0$</u>	<u>Overall r</u>
1	Intercept	466.32	9.51**	0.96
	Slope	19.43	16.93**	
2	Intercept	441.13	12.59**	0.31
	Slope	-1.22	-1.48 N.S. ^a	
<u>Slope comparison</u>		<u>Intercept comparison</u>		
H_o : Slope 1 = Slope 2		H_o : Intercept 1 = Intercept 2		
t-test = 10.40**		t-test = 0.42 N.S. ^a		

^a Not significant.

** 1% level of significance.

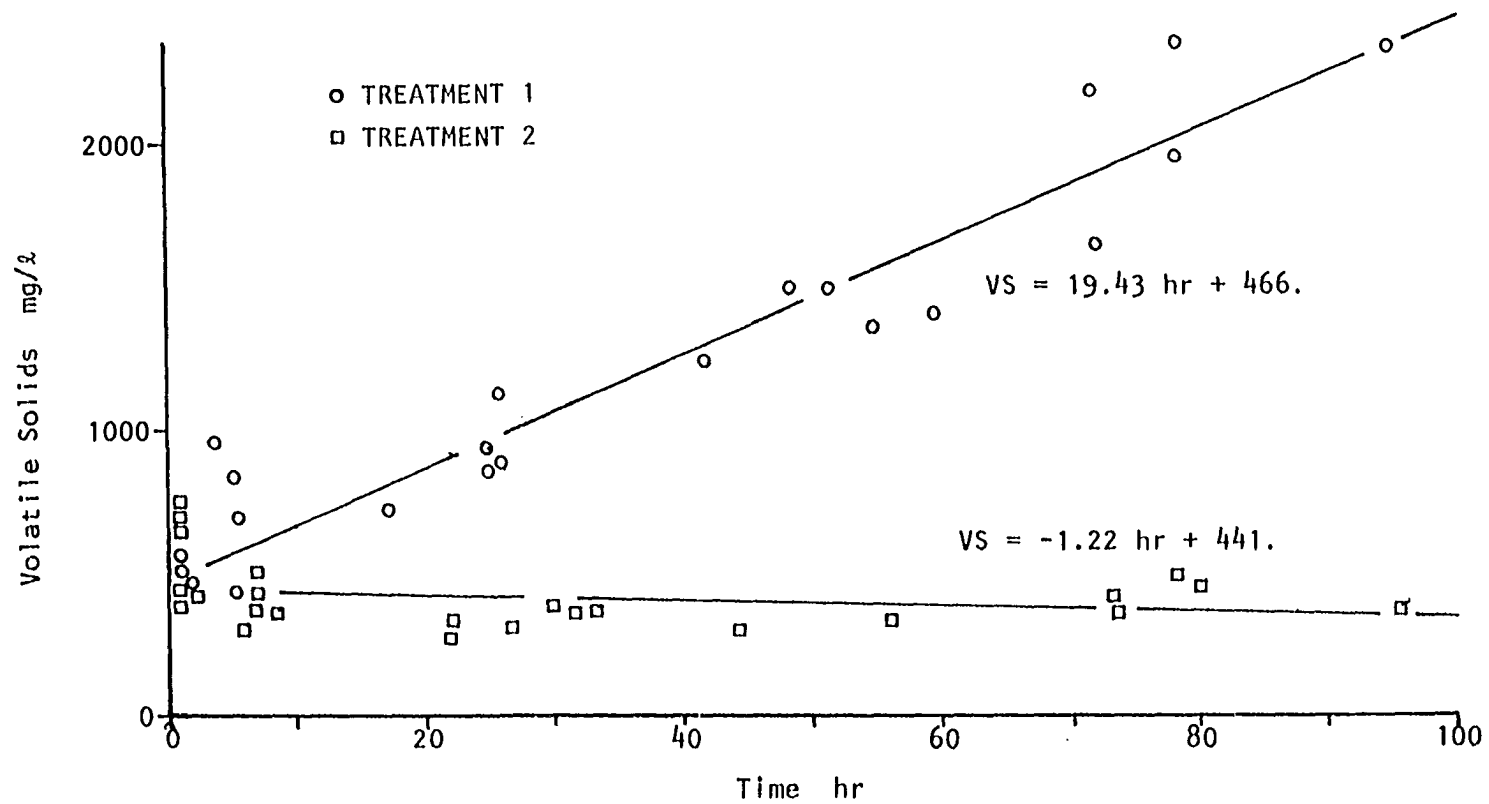


Figure 29. Linear regression of the effect of time on volatile-solids concentrations in the flush water

between the intercepts of the two treatment lines, while the slopes of the two lines were significantly different.

There was a close relationship between the concentrations of TS and VS in the flush water (Table 12, Figure 30). The dissolved-

Table 12. Volatile versus total solids in the flush water

	<u>b value</u>	<u>t-test</u> <u>$H_0: b = 0$</u>	<u>Overall r</u>
Intercept	-458.05	-8.42**	0.96
Slope	0.595	24.27**	

** 1% level of significance.

solids concentration in the ground water in the Poultry Science Center area ranges from 500-1000 mg/l (Twenter and Coble, 1965). Consequently, the intercept of the regression line is not zero because of the presence of those predominantly fixed solids.

Chemical oxygen demand

The chemical oxygen demand (COD) analysis provides another indication of the organic matter in the flush water. COD values include the oxygen demand of biologically resistant organic matter; therefore, COD values are several times greater than biochemical oxygen demand values (BOD) for poultry waste (Miner and Smith, 1975).

COD concentrations in the flush water increased linearly with time during treatment 1, no overflow, and decreased with time during treatment 2, with overflow, (Table 13, Figure 31). The slopes of the two treatment lines are significantly different, while their intercepts are not significantly different. Due to initial concentrations of COD in the recycled lagoon effluent, the intercepts of

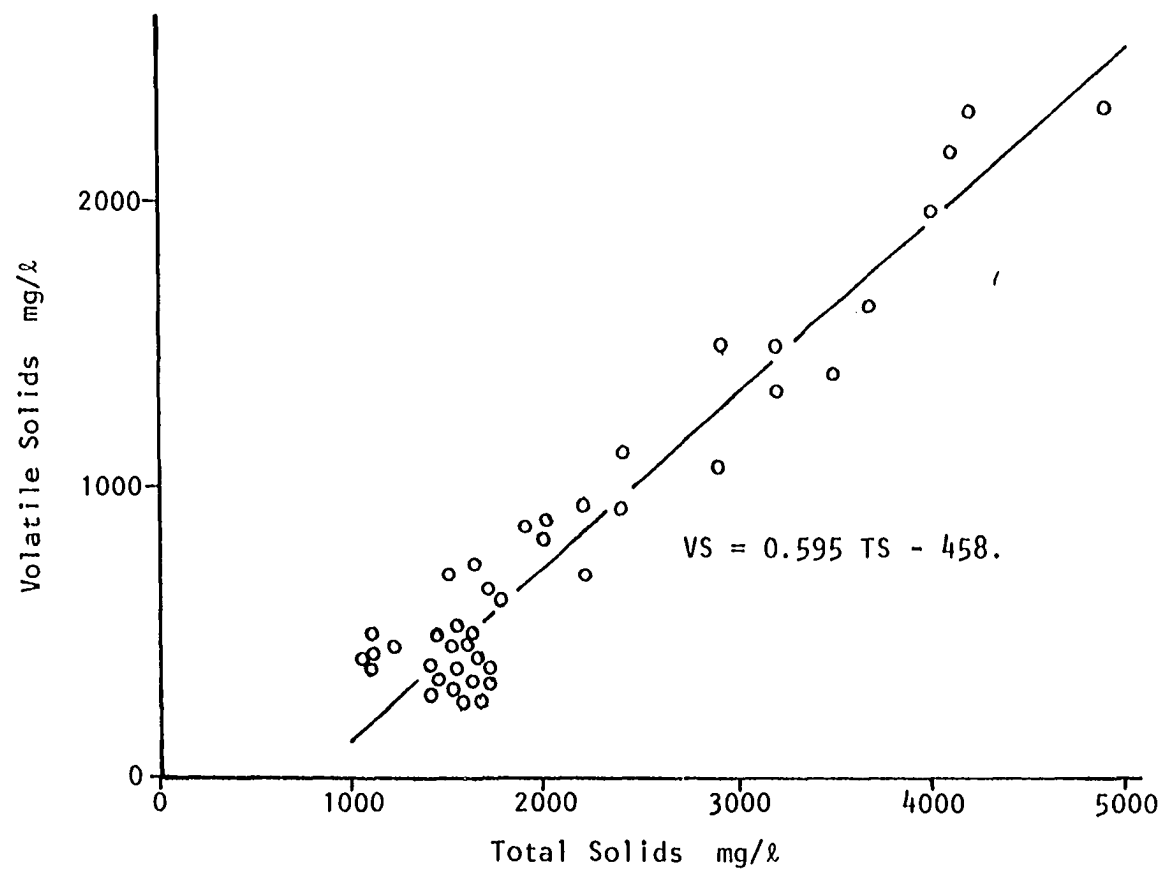


Figure 30. Linear regression of the relationship between volatile-solids and total-solids concentrations in the flush water

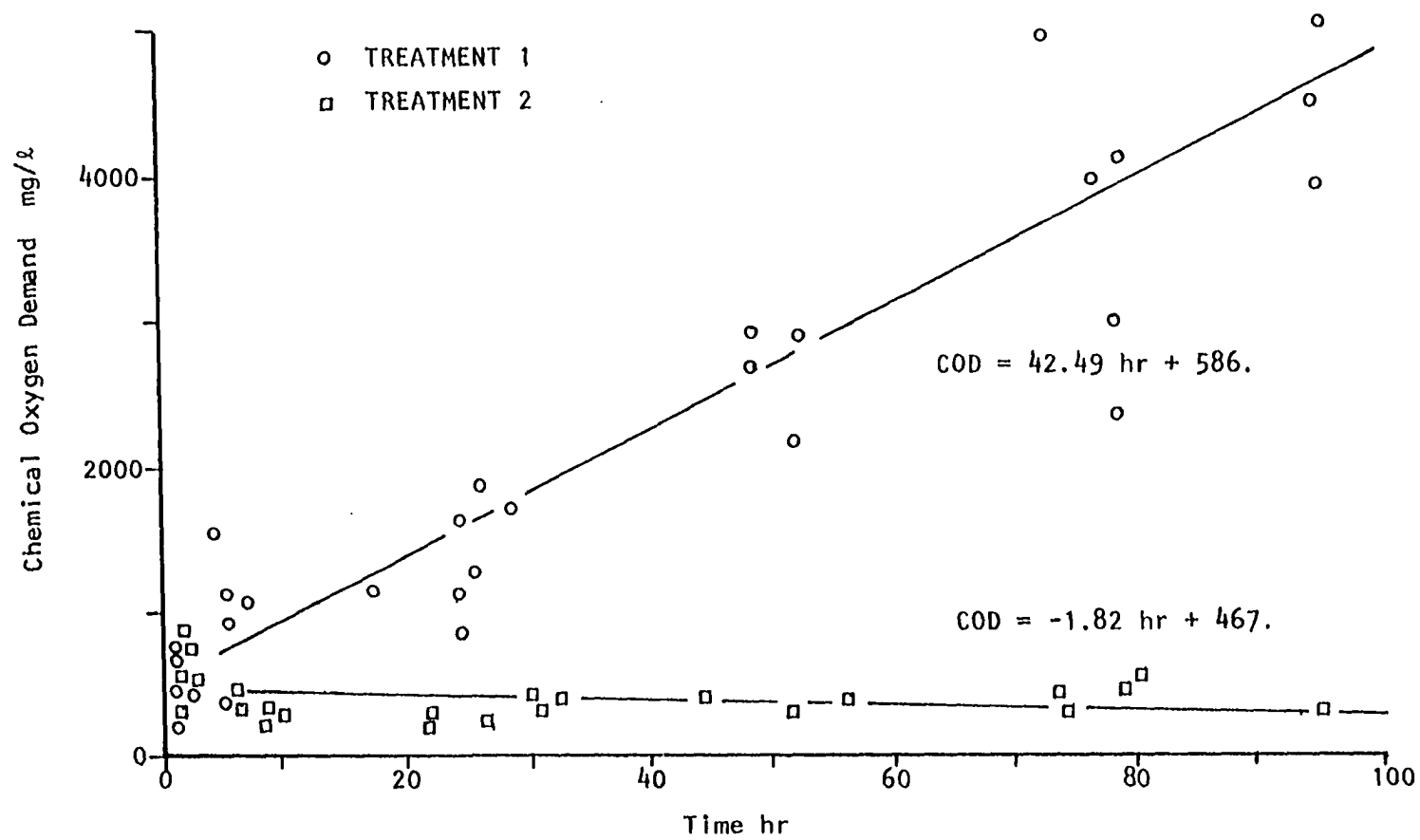


Figure 31. Linear regression of the effect of time on the chemical oxygen demand of the flush water

Table 13. The effect of time on chemical oxygen demand concentrations in the flush water

<u>Treatment</u>		<u>b value</u>	<u>t-test</u> <u>H₀: b = 0</u>	<u>Overall r</u>
1	Intercept	586.06	5.13**	0.96
	Slope	42.49	17.41**	
2	Intercept	466.90	10.59**	0.35
	Slope	-1.82	1.78 N.S. ^a	
<u>Slope comparison</u>		<u>Intercept comparison</u>		
H ₀ : Slope 1 = Slope 2		H ₀ : Intercept 1 = Intercept 2		
t-test = 16.75**		t-test = 0.97 N.S. ^a		

^aNot significant.

** 1% level of significance.

both treatment lines are significantly different than zero.

pH

pH measurements express the hydrogen-ion activity, or more commonly are used to refer to the intensity of the acid or alkaline condition of a solution. Knowledge of pH levels is necessary for determining the free ammonia-N concentration in a solution containing both ammonia and ammonium ions.

Changes in pH with time were not linear for either treatment. Some of the measurements, which confused the relationship between pH and time, were omitted for computer analysis. For example, initial pH measurements were omitted for the treatment 2 analysis, since at time = 0.0 hr, pH = 7.25 and at time = 6.0 hr, pH = 7.88. The second-degree models that indicate the relationship between time and pH for each treatment are given in Table 14 and are shown on Figure 32. The pH changes exhibited in the flush water during either

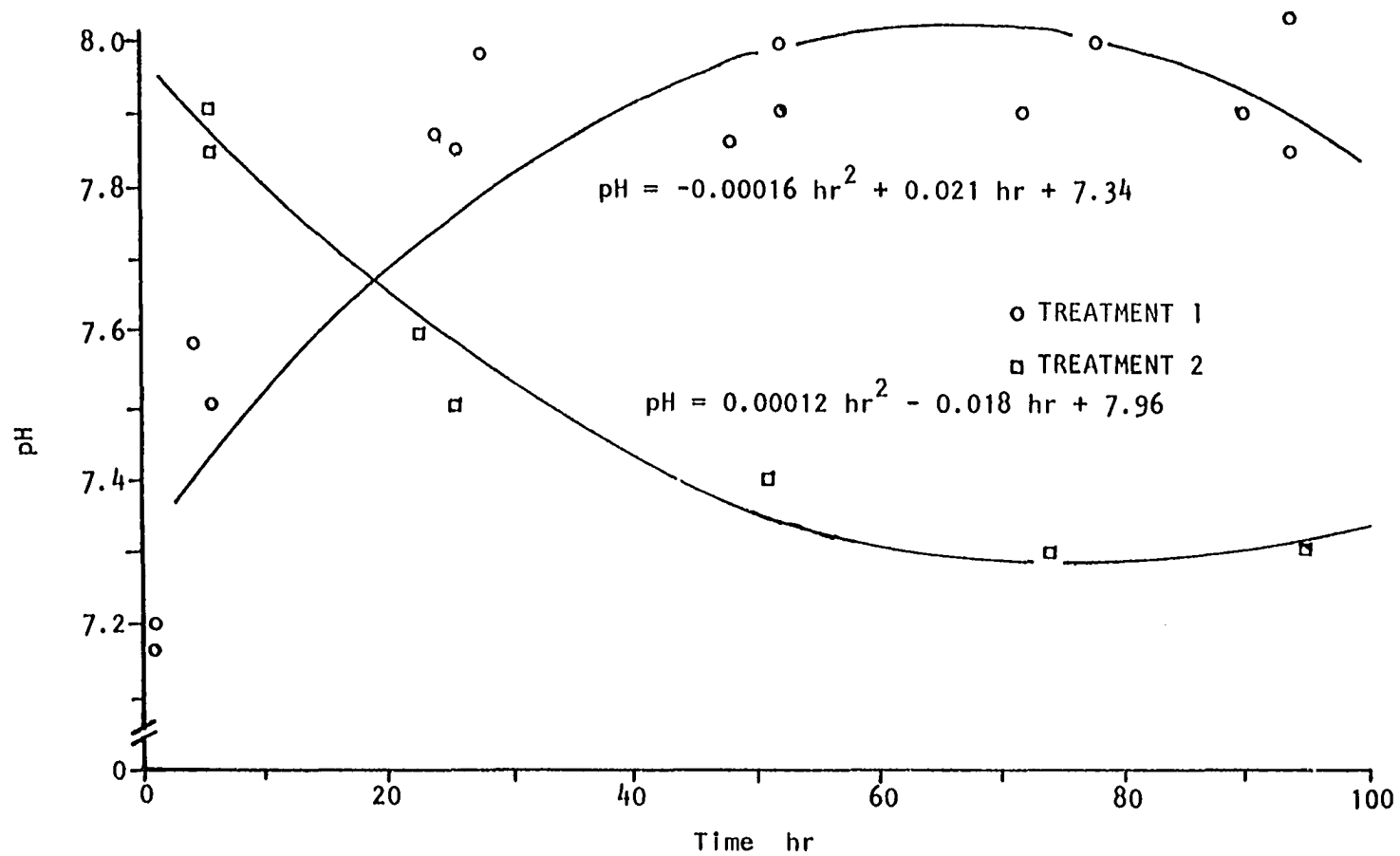


Figure 32. Least squares curve fit of the effect of time on the pH of the flush water

Table 14. The effect of time on the pH of the flush water

Treatment		b value	t-test $H_0: b = 0$	F value	Overall r
1	Intercept	7.34	109.30**		0.91
	(time)	0.021		36.24**	
	(time) ²	-0.00016		19.78**	
2	Intercept	7.96	174.76**		0.98
	(time)	-0.018		109.18**	
	(time) ²	0.00012		20.01**	

** 1% level of significance.

treatment are a result of complex interactions between components of the poultry manure and the flush water. A detailed explanation of the pH changes would require a study that is beyond the scope of this investigation.

Conductivity

Conductivity changes with both the type and number of ions in a solution. Some research has indicated that conductivity is well correlated with dissolved solids; therefore, the ability of conductivity measurement to predict other flush-water qualities was investigated (Ward and Jex, 1969).

Conductivity measurements varied directly with time during treatment 1, no overflow, but changed only slightly during treatment 2 (Table 15, Figure 33). Table 15 shows that the slopes of the two treatment lines are significantly different and the intercepts are also significantly different. The difference between the treatment lines intercepts may be partly due to the small number of samples in treatment 2.

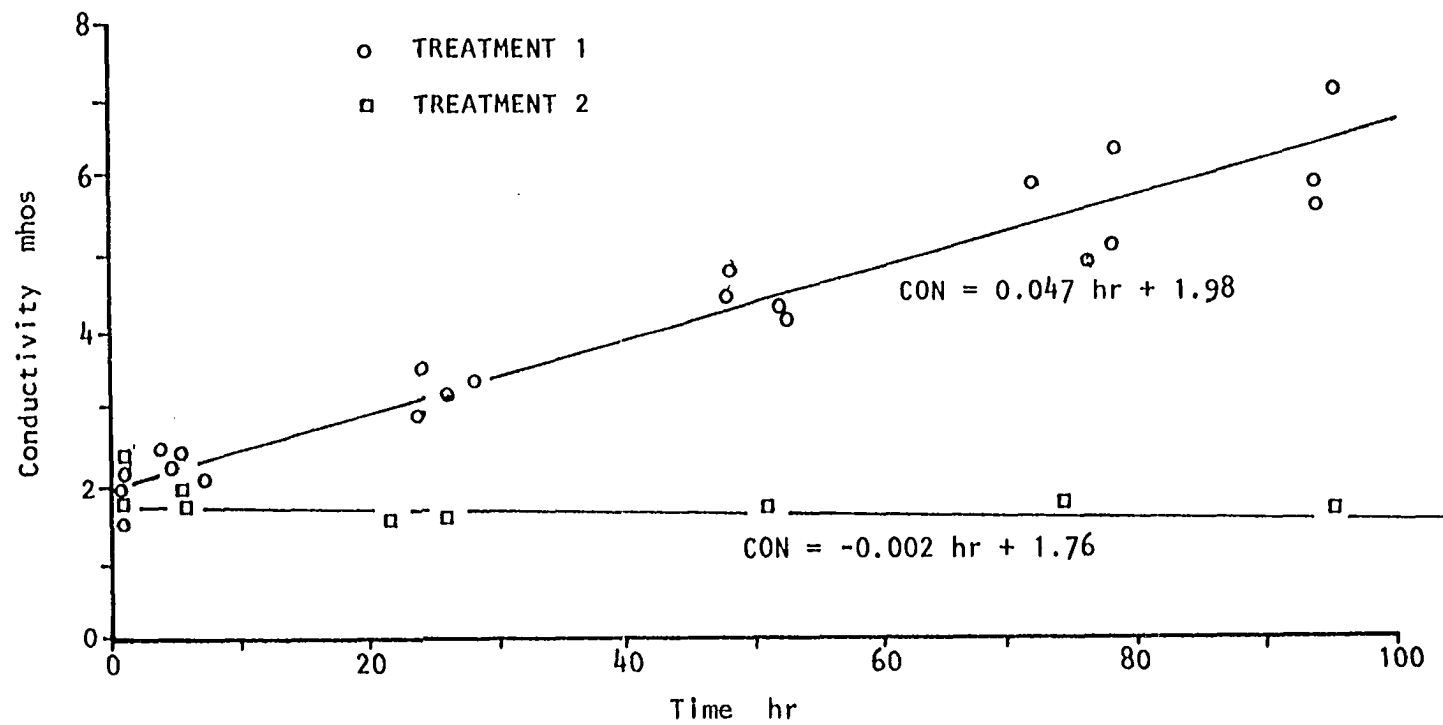


Figure 33. Linear regression of the effect of time on the conductivity of the flush water

Table 15. The effect of time on conductivity measures in the flush water

<u>Treatment</u>		<u>b value</u>	<u>t-test</u> <u>$H_0: b = 0$</u>	<u>Overall r</u>
1	Intercept	1.98	13.63**	0.96
	Slope	0.047	16.74**	
2	Intercept	1.76	23.40**	0.38
	Slope	-0.002	1.10 N.S. ^a	
<u>Slope comparison</u>			<u>Intercept comparison</u>	
H_0 : Slope 1 = Slope 2			H_0 : Intercept 1 = Intercept 2	
t-test = 4595.**			t-test = 8.35**	

^aNot significant.

** 1% level of significance.

The relationship between conductivity and other flush-water quality parameters is shown in Table 16. Conductivity measurements

Table 16. The relationship between conductivity and the other flush-water quality parameters

<u>Dependent variable</u>		<u>b value</u>	<u>t-test</u> <u>$H_0: b = 0$</u>	<u>Overall r</u>
Kjeldahl-N	Intercept	-170.44	10.41**	0.99
	Slope	149.67	32.46**	
Ammonia-N	Intercept	-123.47	8.75**	0.99
	Slope	115.45	29.30**	
Total Solids	Intercept	358.71	3.06**	0.97
	Slope	641.65	18.03**	
Volatile Solids	Intercept	-280.36	5.09**	0.98
	Slope	415.78	24.83**	
COD	Intercept	-1002.00	7.77**	0.98
	Slope	866.62	24.51**	
pH	Intercept	7.38	84.44**	0.59
	Slope	0.09	3.90**	

** 1% level of significance.

were closely related to all other flush-water quality parameters. The close relationships result because all flush-water quality parameters increase uniformly with time, and there was little or no biological action in the storage pit.

The results in Table 16 also reinforce earlier findings about the relationship between total and volatile solids. The average conductivity that corresponds to a zero value for TKN, $\text{NH}_3\text{-N}$, and COD concentrations is 1.12 mhos/cm. When this value is entered into the total solids regression equation, a total solids concentration of 1077 mg/l results. This is close to the range of total dissolved solids that can be predicted in ground water in this area.

Pit temperature

The temperature of the flush water in the recycled water-storage area was measured when flush water samples were taken. Flush-water temperatures and pH values are used for determining the $\text{NH}_3\text{-N}$ concentration in a solution containing both ammonia and ammonium ions. Because of the large volume of water flushed each day, the interaction between pit temperature and air temperature was also investigated.

During both treatments 1 and 2, the pit temperature did not change significantly with time (Table 17). No improvement in significance between time and pit temperature was obtained with higher order models.

The pit temperature of the flush water was significantly affected by the air temperature in the poultry house (Table 18, Figure 34). In the building evaluated, this interaction was not as important as it might be in a building where the flush water is recycled continually

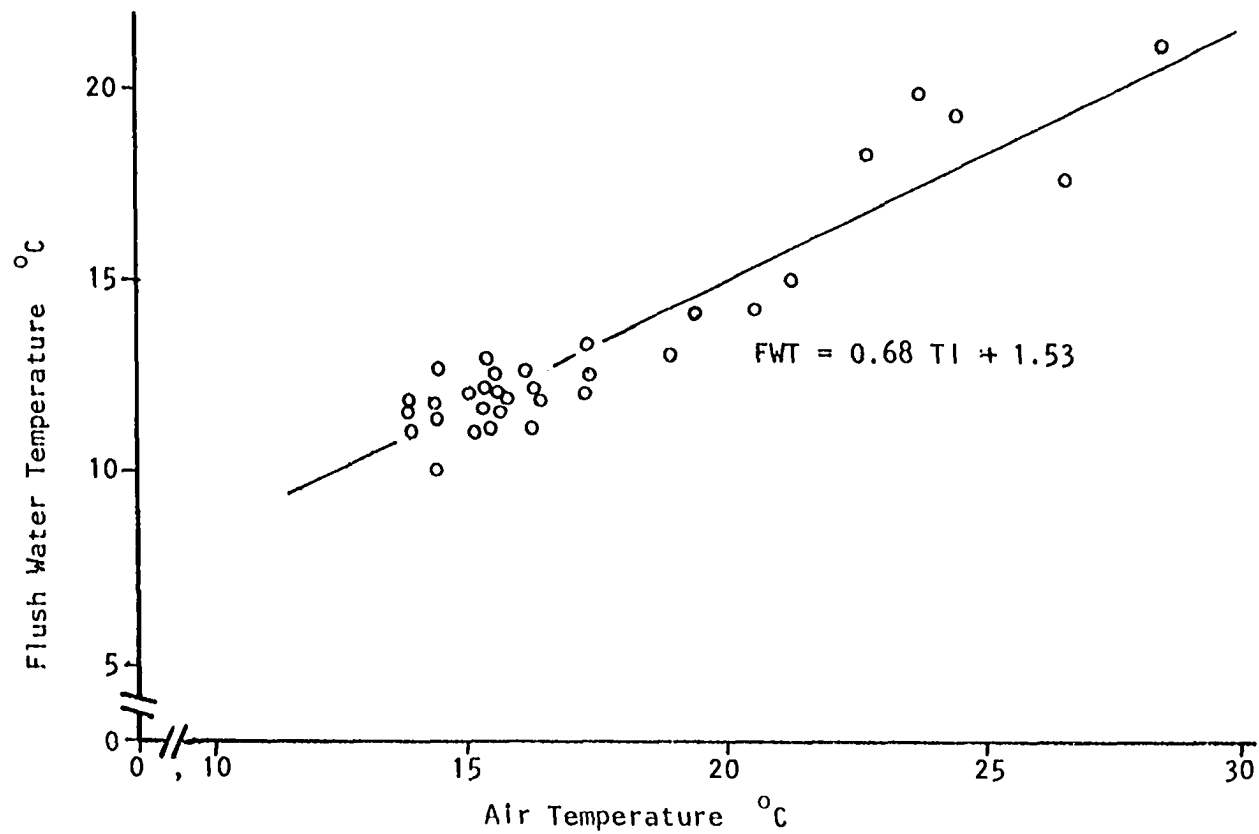


Figure 34. Linear regression of the relationship between flush water temperature and the air temperature in Unit D

Table 17. The effect of time on the pit temperature of the flush water

<u>Treatment</u>		<u>b value</u>	<u>t-test</u> <u>H₀: b = 0</u>	<u>Overall r</u>
1	Intercept	11.37	27.56**	0.33
	Slope	0.07	1.84 N.S. ^a	
2	Intercept	11.69	122.11**	0.47
	Slope	0.02	1.87 N.S. ^a	
<u>Slope comparison</u>			<u>Intercept comparison</u>	
H ₀ : Slope 1 = Slope 2			H ₀ : Intercept 1 = Intercept 2	
t-test = 1.00 N.S. ^a			t-test = 0.37 N.S. ^a	

^aNot significant.

** 1% level of significance.

Table 18. The effect of air temperature on the pit temperature of the flush water

	<u>b value</u>	<u>t-test</u> <u>H₀: b = 0</u>	<u>Overall r</u>
Intercept	1.53	5.12**	0.94
Slope	0.68	16.95**	

** 1% level of significance.

from an outside-storage area or lagoon. Continuous recycling of colder flush water may reduce the inside air temperature during the winter. Similarly, a cooler flush water may aid in reducing the air temperature during the summer, both directly by sensible cooling and indirectly by evaporation. The interaction between air temperature and pit temperature is a result of the large surface area of the flush trays, which can serve as a heat sink. The flush trays can slowly absorb heat from the surrounding air between flushes and then release it rapidly to the flush water as it passes over the

trays. Ventilation systems should be designed to use this interaction to the greatest benefit by reducing air velocities over the trays in the winter to reduce heat transfer, while increasing air velocities over the trays in the summer to aid the heat transfer from the air.

Air Quality

Temperature

The analysis of the air-temperature data showed that the air temperature inside the poultry house was most significantly affected by the outside-air temperature (Table 19, Figure 35). As the outside-air

Table 19. The effect of outside-air temperature on the air temperature inside the poultry house

	<u>b value</u>	<u>t-test</u> <u>$H_0: b = 0$</u>	<u>F value</u>	<u>Overall r</u>
Intercept	14.97	41.64**		0.97
(T0)	0.0127		423.8**	
(T0) ²	0.0124		99.1**	

** 1% level of significance.

temperature decreased, the inside-air temperature was maintained by the heater in Unit D; when outside-air temperature increased, the inside-air temperature also increased. This interaction could have been predicted using conventional temperature-balance equations; however, these balances would have predicted that the inside-air temperature should be greater than the outside-air temperature. In Unit D, The air temperature remained below the outside-air temperature when the outside air-temperature exceeded 21°C.

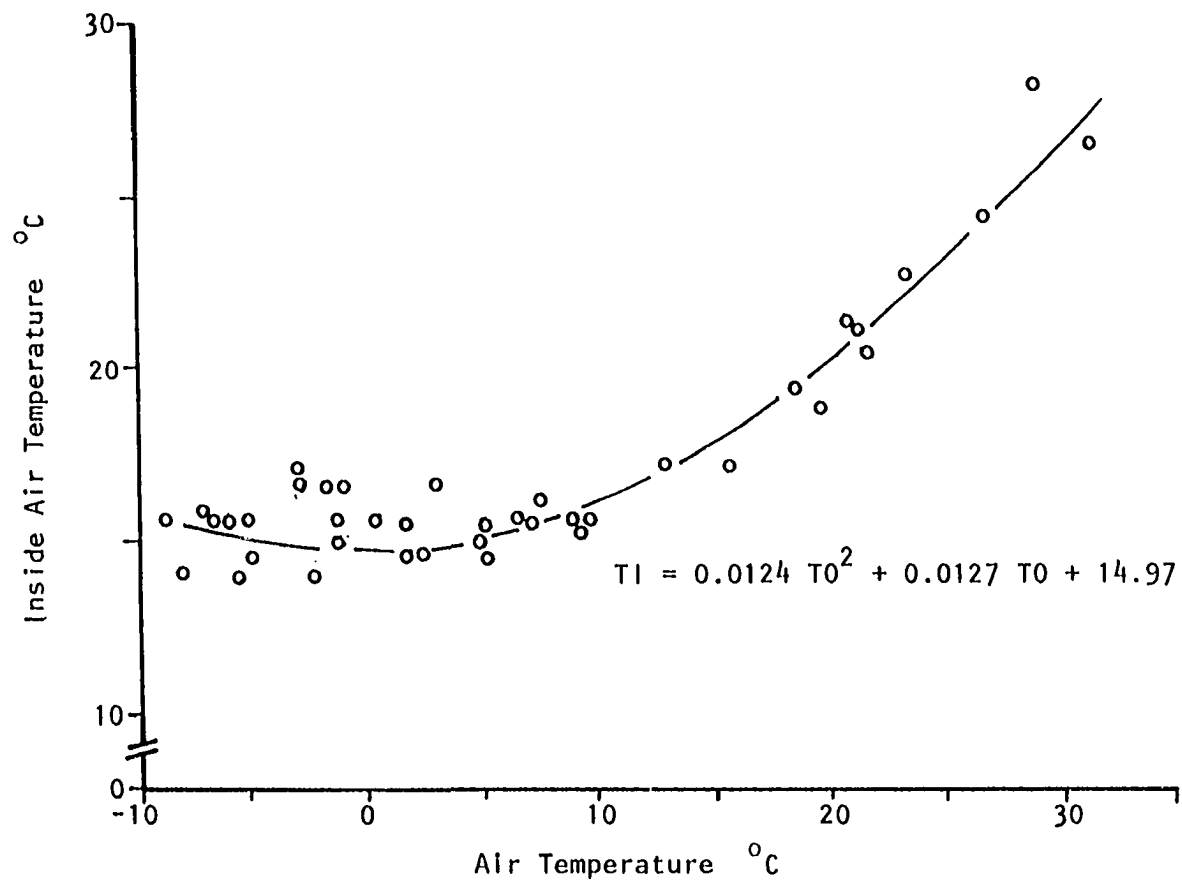


Figure 35. Least squares curve fit of the relationship between inside and outside air temperatures

The cooling effect was a combination of sensible and evaporative cooling. The psychometric chart in Figure 36 shows some inside and outside air temperature and humidity combinations measured during the experiment. Because they closely follow the wet bulb lines, it seems logical to assume that the major cooling effect resulted from evaporation although some sensible cooling may also be noted.

Relative humidity

The relative humidity inside Unit D was not well correlated with any other air-quality parameter measured. Outside relative humidity had the greatest influence on the inside relative humidity with the two being directly correlated (Table 20, Figure 37). The

Table 20. The effect of outside relative humidity on the inside relative humidity

	<u>b value</u>	<u>t-test</u> <u>$H_0: b = 0$</u>	<u>Overall r</u>
Intercept	56.53	14.81**	0.54
Slope	0.19	3.88**	

** 1% level of significance.

regression analysis in Table 20 is not a useful approximation of the inside relative humidity at Unit D because the evaporative cooling during warm weather added humidity and the use of the heater in cool weather allowed the relative humidity inside to remain low as a result of the higher ventilation rates maintained.

The relationship between atmospheric-ammonia concentrations and relative humidity shown in other research was not noted in this research. However, no relative humidities below 60% were measured

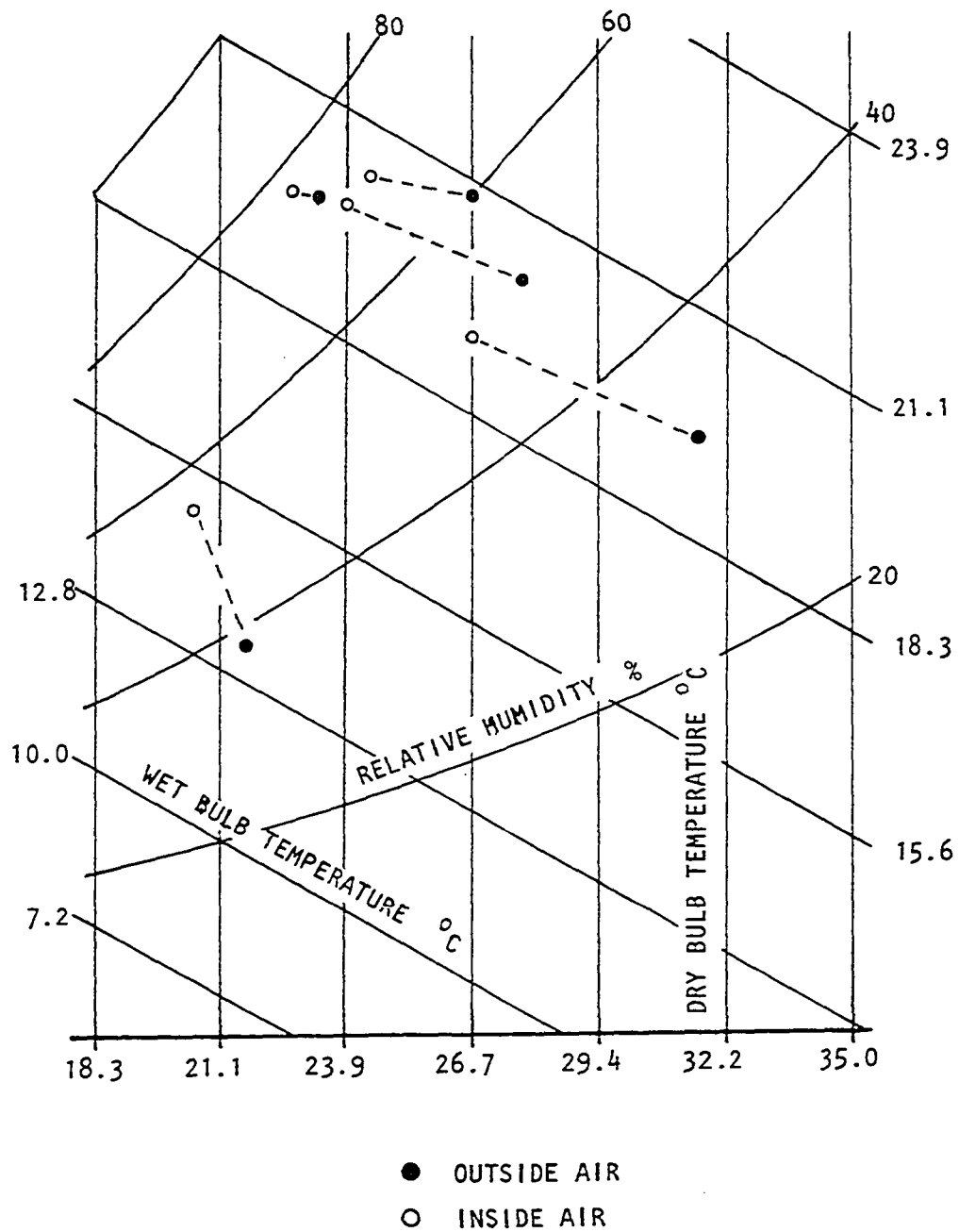


Figure 36. Inside and outside air conditions presented on a psychrometric chart to show adiabatic cooling

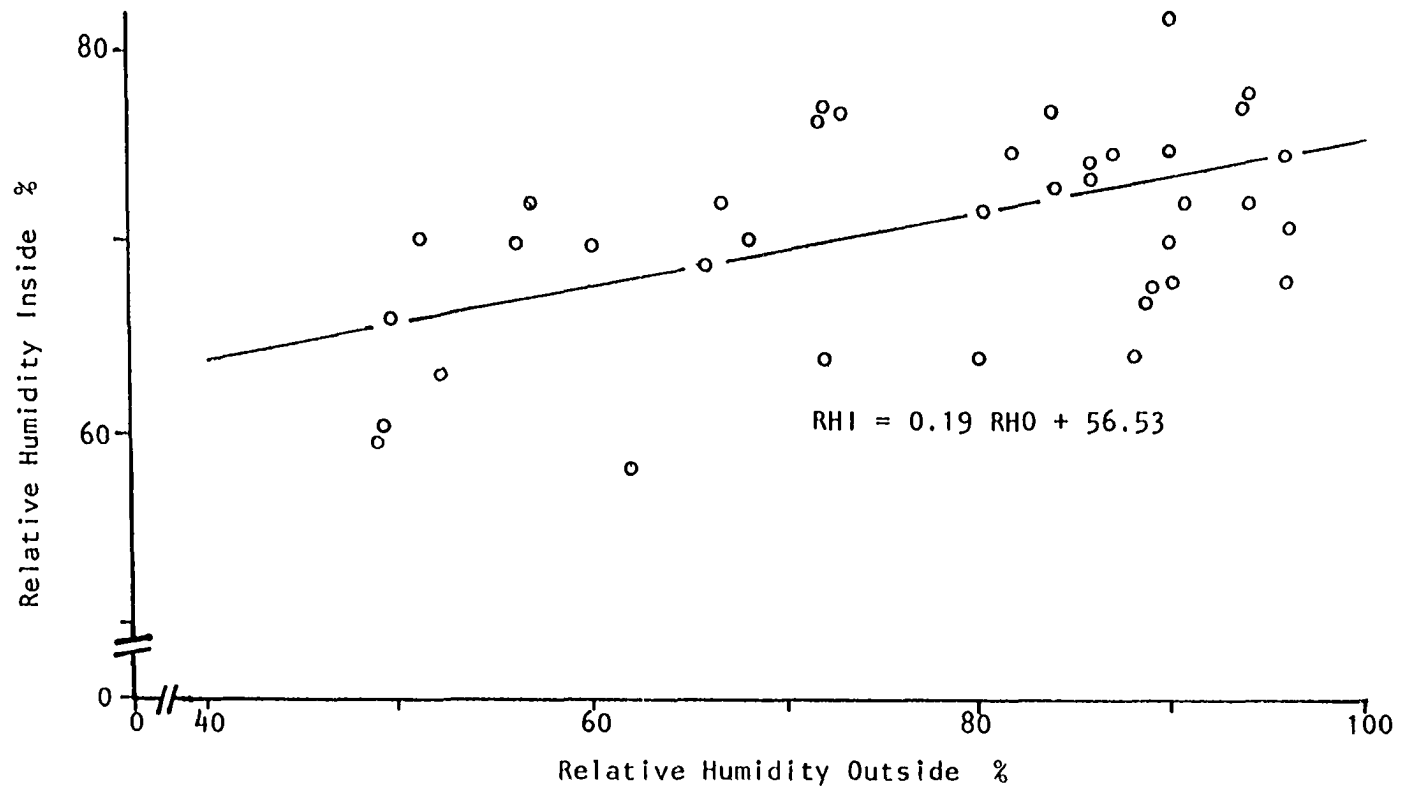


Figure 37. Linear regression of the relationship between inside and outside relative humidity

inside the building, the condition existing in the earlier reported research when this relationship was noticeable.

Atmospheric ammonia

Atmospheric-ammonia concentrations were measured to give an indication of the overall effectiveness of the flush system in Unit D. Of primary interest was the effect of the flush-water quality on atmospheric-ammonia concentrations.

An indication of the interaction between the flush-water quality and atmospheric-ammonia concentration was obtained from the linear regression of ammonia versus time for each treatment. Ammonia concentrations increased linearly with time during treatment 1, while showing no significant change during treatment 2 (Table 21, Figure 38).

Table 21. The effect of time on atmospheric-ammonia concentrations

<u>Treatment</u>		<u>b value</u>	t-test <u>$H_0: b = 0$</u>	<u>Overall r</u>
1	Intercept	1.50	7.20**	0.59
	Slope	0.01	3.57**	
2	Intercept	1.23	8.43**	0.49
	Slope	-0.004	1.24 N.S. ^a	
<u>Slope comparison</u>			<u>Intercept comparison</u>	
$H_0: \text{Slope 1} = \text{Slope 2}$			$H_0: \text{Intercept 1} = \text{Intercept 2}$	
t-test = 3.58**			t-test = 1.07 N.S. ^a	

^aNot significant.

** 1% level of significance.

The slopes of the treatment regression lines were significantly different, while the intercepts were not.

The correlation coefficients of both treatment regression lines

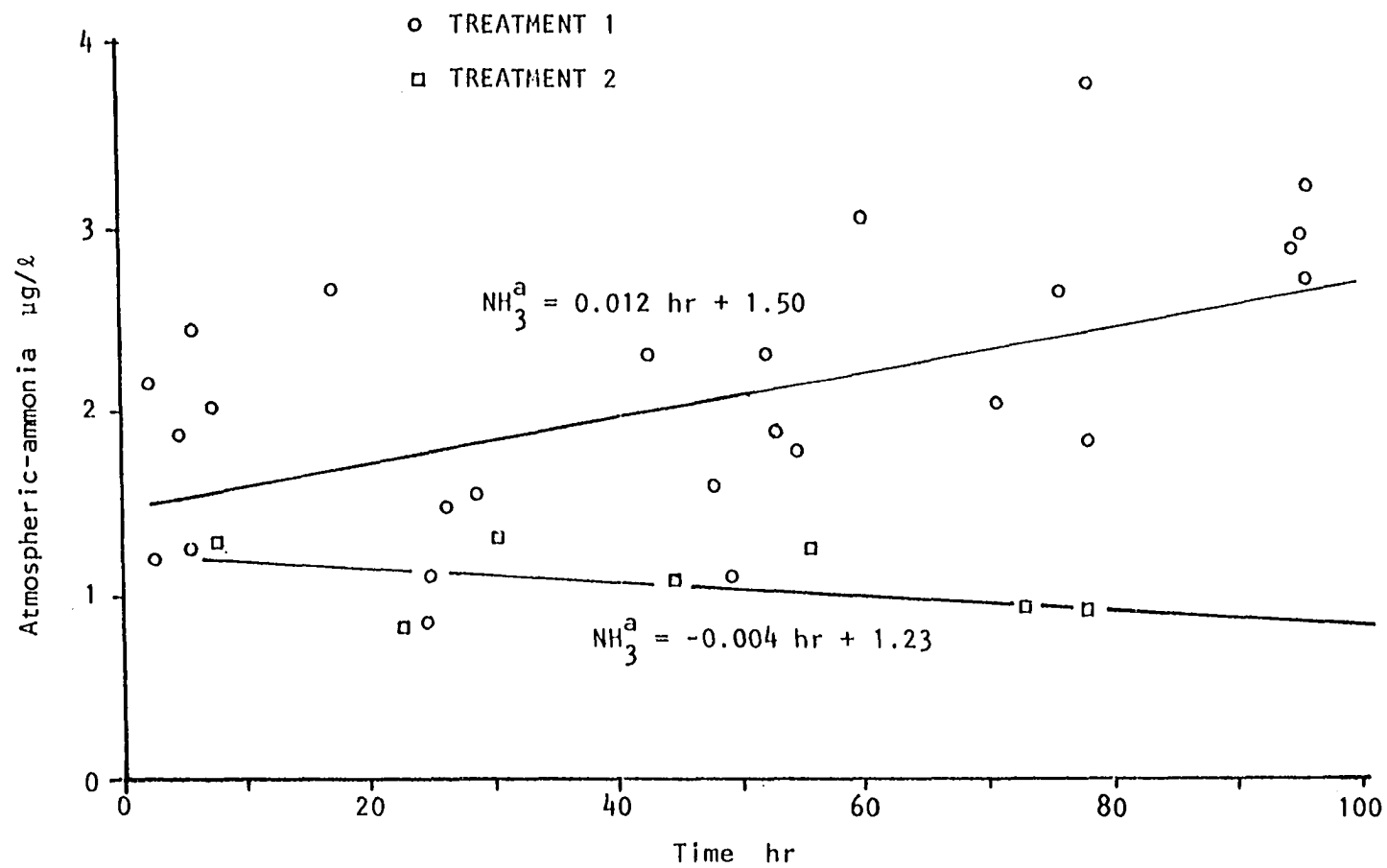


Figure 38. Linear regression of the effect of time on atmospheric-ammonia concentrations

were low but showed the same general trends as some flush-water quality parameters.

The interaction between atmospheric-ammonia concentrations and ammonia-nitrogen concentrations in the flush water was evaluated by a linear regression model (Table 22, Figure 39). The slope of

Table 22. The effect of ammonia-nitrogen concentrations in the flush water on atmospheric-ammonia concentrations

	<u>b value</u>	<u>t-test</u> <u>$H_0: b = 0$</u>	<u>Overall r</u>
Intercept	1.15	5.71**	0.72
Slope	0.0029	4.91**	

** 1% level of significance.

the linear regression was significantly different from zero which indicates some form of ammonia desorption is occurring. The intercept was also significantly different than zero because ammonia is being released by fresh manure on the flush tray. This release of ammonia by fresh manure results in a "background" concentration of atmospheric ammonia, a concentration which is not affected by flush-water-quality parameters.

Further analysis indicated that atmospheric-ammonia concentrations were also related to TKN, TS, VS, and COD concentrations. However, these interactions are basically a result of the effect of time on all the factors considered.

No significant correlation could be found between the ventilation rate and atmospheric-ammonia concentrations. Research reporting this correlation was conducted on buildings in which much higher concentrations of atmospheric ammonia were measured. The low at-

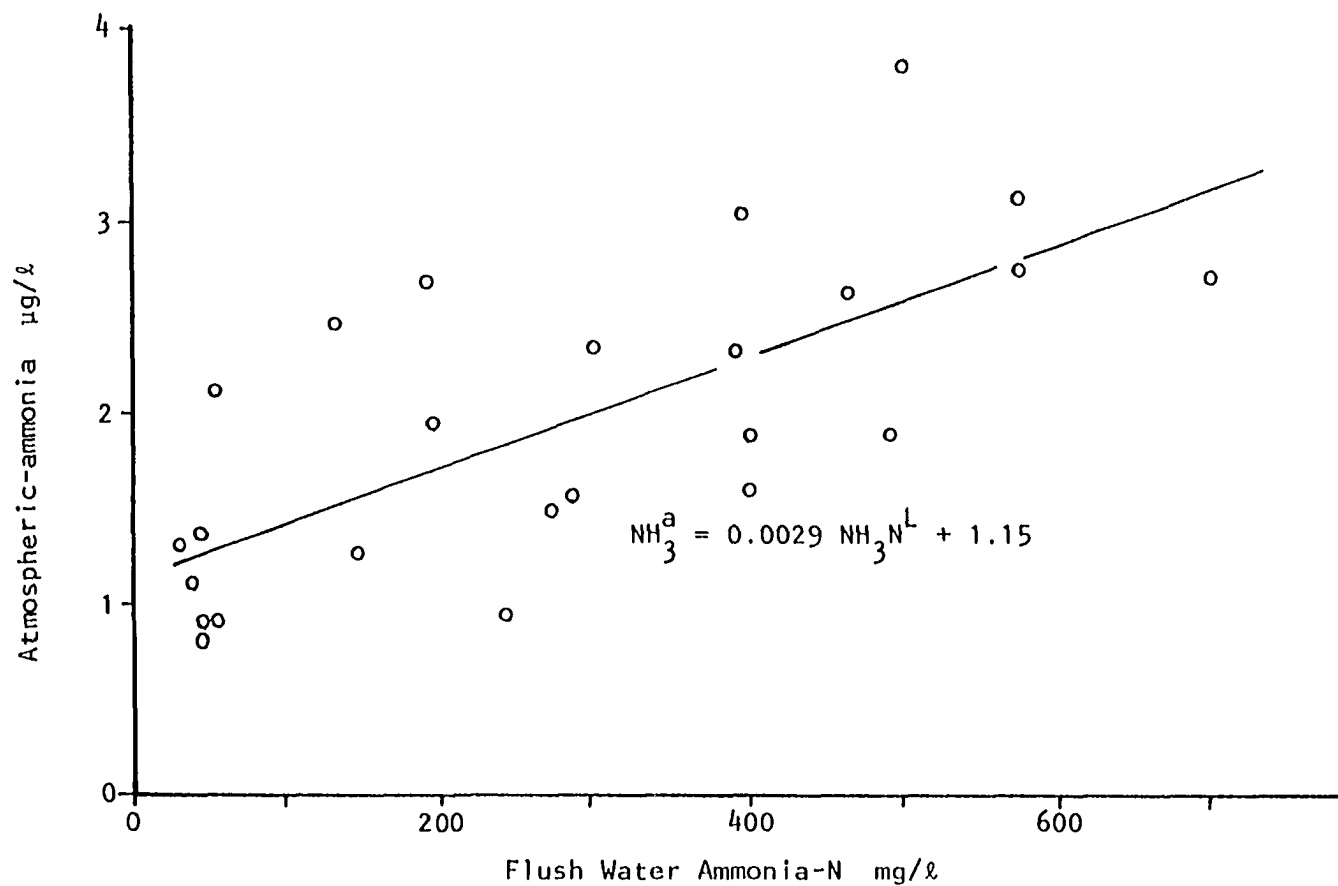


Figure 39. Linear regression of the relationship between atmospheric-ammonia and ammonia-nitrogen in the flush water

mospheric ammonia in Unit D resulted in the ventilation rate having no significant effect on measured concentration.

OBSERVATIONS

Observations of the flushing system indicated that, as initially installed, the 720 l flush every 25 minutes did an adequate job of keeping the trays clean. The connection between the two supply tanks was then closed off and the resulting 420 l flush, if every 15 minutes, was also observed to do an adequate job of tray cleaning. A later modification in the recycling system resulted in a reduction in the flushing frequency of the 420 l supply to once every 35 minutes which did not appear to provide adequate cleaning. Presently, all flush tanks at Unit D have been modified to flush 420 l as it is unlikely that a 720 l flush will do a better job of cleaning the trays because the flushing frequency is reduced to once every 60 minutes. Although a flushing system will have a number of acceptable combinations of flushing frequency and duration for proper cleaning, the flushing frequency appears to have the larger influence on cleaning ability.

The flush trays at Unit D required additional cleaning monthly to remove accumulated manure along the edges and the vertical lips of the trays (Figure 14). Removal of the accumulated manure was accomplished by loosening it with a high-velocity jet of water. Once loosened, the manure was removed during the next normal flushing of the trays. It is emphasized that manure accumulations at Unit D were confined to the tray edges and vertical lips, and other areas remained free of manure accumulations at all times.

Although the vertical lips were installed partially to serve as flow dividers and prevent meandering, their usefulness for this

purpose is questionable. Manure on the trays at Unit D appeared to be randomly deposited by the birds, with the exception of an apparent effort by certain birds to overshoot the tray and place their deposit on the floor. The absence of concentrated manure deposits allows the flush water to move around the small deposits and remove them; therefore, forced meandering of the flush water appears unlikely. The tray supports used (Figure 15) to provide a method of leveling the tray to prevent meandering caused improper installation. It appears, therefore, that where vertical lips are required to increase tray rigidity, they should be constructed to extend downward from the trays.

Manure accumulation along the tray edges could be prevented by widening the tray beyond the edge of the cage 20 cm or more. Observations indicate that the extra width of tray required can be minimized by keeping the trays as close to the bottom of the cages as is practical to construct. Alternatively, the edge of the tray could be designed to minimize manure accumulation and allow easy cleaning with a hand scraper.

The three dosing siphons provided an even distribution of water over the trays during flushing; however, the dosing siphons, as originally installed, required monthly cleanings of the trap-charging holes, (Figure 19). Siphon-breaking holes were drilled in the traps (Figure 19) which perform a function similar to the trap-charging holes but do not require frequent cleaning. The dosing siphons have performed properly since the addition of these siphon-breaking holes although the flushing rate was decreased slightly. Installation

of a dosing siphon, as shown in Figure 40, would eliminate the need for both the trap-charging and siphon-breaking holes.

The feather-chopper pump was used before cleaning the recycled-water-storage area to also agitate the manure that had settled. Feather chopping with the pump could only be done by allowing the pump to operate while the water was drained out of the building. The pump was not able to pull floating feathers from the water surface into its inlet and would lose its prime before the water level fell enough to float the feathers into its inlet. Installation of the pump inlet in a horizontal plane might correct this deficiency. Too, the pump was not scheduled to operate at intervals during the day as had been originally planned (Figure 18) because such operation increased the solids concentration of the flush water and plugged the screens by the wet well (Figure 13). These screens, which had been installed to prevent feathers from entering the recycle pump, required biweekly cleanings. During treatment 1, no dilution, the screens became blocked to the extent that the water level in the storage was 15 cm above the level of water in the wet well. The material blocking the screens appeared to be a mixture of poultry manure particles and feathers. Addition of dilution water, treatment 2, reduced the screen-blockage problems by continually removing some of the poultry-manure particles. Using an open-impeller pump for recycling may eliminate the need for screens; however, the dosing siphons would simultaneously have to be designed without a trap-charging hole or they would not perform properly.

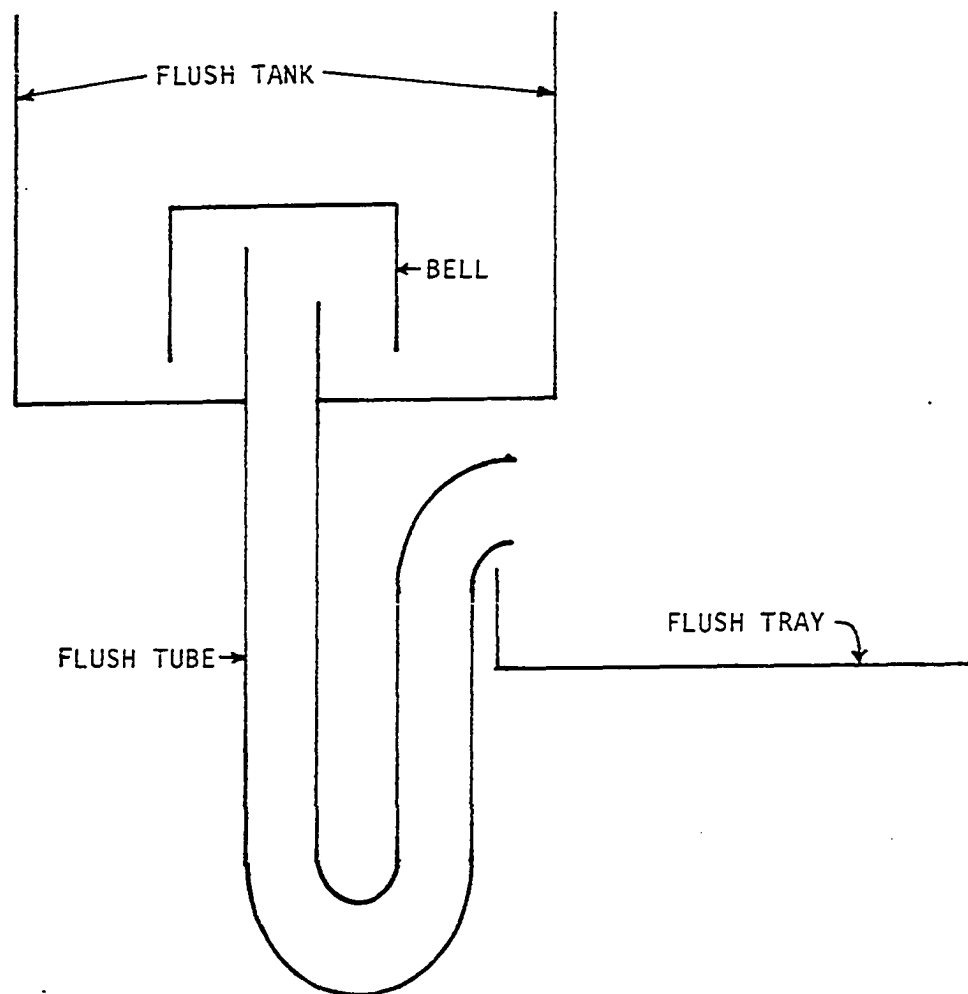


Figure 40. Dosing siphon configuration which does not require a trap-charging hole or a siphon breaking hole

DISCUSSION

Internal Environment

In the review of literature, it was shown that ammonia nitrogen in a liquid could be released as atmospheric ammonia desorption if the partial pressure of ammonia in the liquid were greater than the partial pressure of ammonia in atmosphere. Statistical analysis of the data measured at Unit D verified that a correlation existed between the flush water ammonia-nitrogen concentration and the atmospheric-ammonia concentration.

By the use of the equations developed in the review of literature, it is possible to evaluate the effect of the measured conditions in Unit D on desorption. Under conditions during treatment 1, no overflow, the following assumptions are used to determine the difference in partial pressures of ammonia in the atmosphere and the flush water: time = 96 hr, ammonia-nitrogen concentration in the flush water = 622 mg/l, pH = 8.0, flush water temperature = 12.7 °C, atmospheric ammonia concentration = 275 µg/l, air temperature = 15.6 °C, relative humidity = 70%. Using Figure 7a and Equation 12, the pressure of atmospheric ammonia calculated is 3.87×10^{-6} atm. The pressure of the ammonia nitrogen in the flush water, as calculated using Equations 22, 20, 24, and 13 is 9.34×10^{-6} atm. As shown in Equation 9, the pressure differential of concern in the desorption equation is the pressure of ammonia nitrogen in the flush minus the pressure of the atmospheric ammonia. The positive pressure differential of 5.47×10^{-6} atm indicated that desorption of ammonia is occurring

under the above conditions.

A similar analysis of conditions during treatment 2, with overflow, can be made, whereby the following assumptions apply: time > 0 , ammonia nitrogen concentration in the flush water = 46.4 mg/l, pH = 7.30, flush water temperature = 12.7 °C, atmospheric ammonia concentration = 1.23 µg/l, air temperature = 15.6 °C, relative humidity = 70%. By using these assumptions in the previously noted equations, the resulting pressure of atmospheric ammonia is 1.73×10^{-6} atm. The negative pressure differential of -1.59×10^{-6} atm indicates that under these conditions absorption rather than desorption occurs. The absorption of atmospheric ammonia by the flush water provides a reasonable explanation of the low concentrations of atmospheric ammonia measured in Unit D during treatment 2.

The preceding examples show that a flushing system can either increase or reduce atmospheric-ammonia concentrations in a poultry building due to interchange of ammonia with the flush water. As shown in Equation 9, the rate of absorption or desorption is controlled by the pressure differential of the ammonia as calculated above, the liquid surface area and the diffusion coefficient. The surface area and diffusion coefficient for the two main exchange areas for desorption or absorption in Unit D are shown in Table 23. Relative velocity between the air and the water surfaces was controlled by air flow over the still water in the recycled-water-storage area and by the flush-water velocity during flushing. Table 23 shows that flushing the trays accounts for most of the absorption or desorption

Table 23. Recycle water storage area and flushing water desorption coefficients

	<u>Recycle water storage area</u>	<u>Flushing water on trays</u>	<u>Total</u>
Area (cm) ²	96,500	1,080,000	
Air velocity over water surface (cm/sec)	minimal	61	
K _g (g/hr-cm ² -atm)	0.042	3.32	
Time (min/hr)	60	3	
A K _g Time (g/hr-atm)	4,050	178,850	182,900
Percent of total	2.2	97.8	

capacity (97.8%) of the water in the building while only occurring for approximately 5% of the time.

In the preceding analysis, the pH of the flush water was the factor found to have the most predominant effect on the pressure of ammonia in the flush water. The ammonia fraction in the flush water varies from 0.022 at a pH of 8.00 to 0.005 at a pH of 7.30. Therefore, the design and operation of a flushing system for poultry should maintain a low pH to be most effective in reducing desorption and increasing absorption of ammonia. Preliminary trials of flush-water aeration indicate that continuous aeration increases pH values from 7.4 to 8.3; therefore, flushing systems should be designed to prevent excessive aeration before and during flushing. The increase in pH values for aerated flush water tends to indicate that the chemical reactions which may be occurring during aeration were responsible for part of the change in pH values noted during treatment 2.

Flushing frequency and duration will affect atmospheric-ammonia

absorption or desorption because of their direct effect on the length of time the flush water is on the trays. The values shown in Table 25 can be used as an illustration of this effect; doubling the time the flush water is on the trays results in a 198% increase in the total AK_g value. Increasing the duration of flushing would be difficult to regulate with the type of flush siphons used in this research but the flushing frequency could be controlled easily by controlling the filling rate. However, there is a minimum flushing frequency and duration which adequately cleans the flush trays that must be maintained.

During cold weather, the requirements for ammonia absorption by the flushing water, i.e., low pH and frequent flushing, may run counter to temperature-control requirements. Water recycled from a lagoon would enter the building at a temperature close to 0°C . In the flush system evaluated in this research, the flush-water temperature increased quickly to 12.7°C during the winter and remained at the temperature while in the building. However, under the conditions of continually recycling flush water at 0°C , sensible cooling of the air surrounding the flush trays would occur. The sensible heat loss would result from the flush water cooling the trays, then the trays would slowly remove heat from the surrounding air between flushes; this mechanism is in contrast to the flush water having a direct effect, as in ammonia desorption. The trays have the controlling effect on air temperature because the rate of heat transfer between the tray and water surfaces and the air is likely to be much lower than the rate of heat transfer between the flush water and the trays.

While sensible cooling of the air in the winter is a problem, it is desirable in the summer. As indicated by the results, some sensible cooling will occur in the summer. This effect is greater in a building designed to recycle continuously from a lagoon because the pit-water temperature responds quickly to the air temperature in the building, whereas the lagoon is slow to respond to changes in the outside air temperature due to its large mass. No attempt was made in this study to increase the sensible and evaporative cooling of the air in Unit D. Installation of circulating fans over the flush trays to increase the rate of heat transfer between the air and the trays should be effective aids to cooling. However, installation of circulating fans over the trays would also increase the drying rate of the manure and thus result in a need for more frequent flushing to obtain proper cleaning.

Solids Concentration in the Flush Water

Recycling flush water from a small storage area located within a building, as in Unit D, is being considered by some producers as a method of applying a flushing system without the use of a lagoon. The results from this study show that the solids concentration in the flush water will increase linearly with time during the first 4 days, but do not reveal what happens after this length of time. Further, these results properly apply only to flushing systems the same size as Unit D and might therefore not give a true projection for larger or smaller systems.

To overcome these limitations, a model (Appendix B) was developed to predict the solids concentration in the flush water at any time

for any size in-house-recycling system used for any types of domestic livestock. One of the difficulties in predicting the solids concentration in the flush water for a recycling system is determining the change in liquid volume above the settled solids with time, Figure 41. Both volumes shown contain a solid and liquid fraction in proportion to their solids concentration. In the case of settled solids from poultry manure, the solids concentration decreases from 25% as defecated on the trays to 15-18% in storage, which requires the addition of liquid (Ludington and Sobel, 1964). Therefore, the settled-solids volume in Figure 41 increases faster than the total volume, thereby decreasing the liquid volume above the settled solids in which the dissolved and suspended solids are added for poultry manure. The model allows for changes in the solids concentration of settled solids and could be applied to systems in which the solid concentration after settlement increases.

The model also allows for the continual addition of dilution water into the storage area and thereby imposes a maximum total volume on the system with the excess liquid overflowing (Figure 41). As the excess liquid overflows, it carries some dissolved and suspended solids with it which reduces the amount of solids in the liquid volume above the settled solids. Overflow can be induced without dilution water by the addition of manure if the storage-area volume is close to its maximum value at the start.

Poultry manure has been characterized for changes in density with the solids concentration and percent solids settlement in recent publications (Chen and Hashimoto, 1975; Moore et al., 1975). Changes

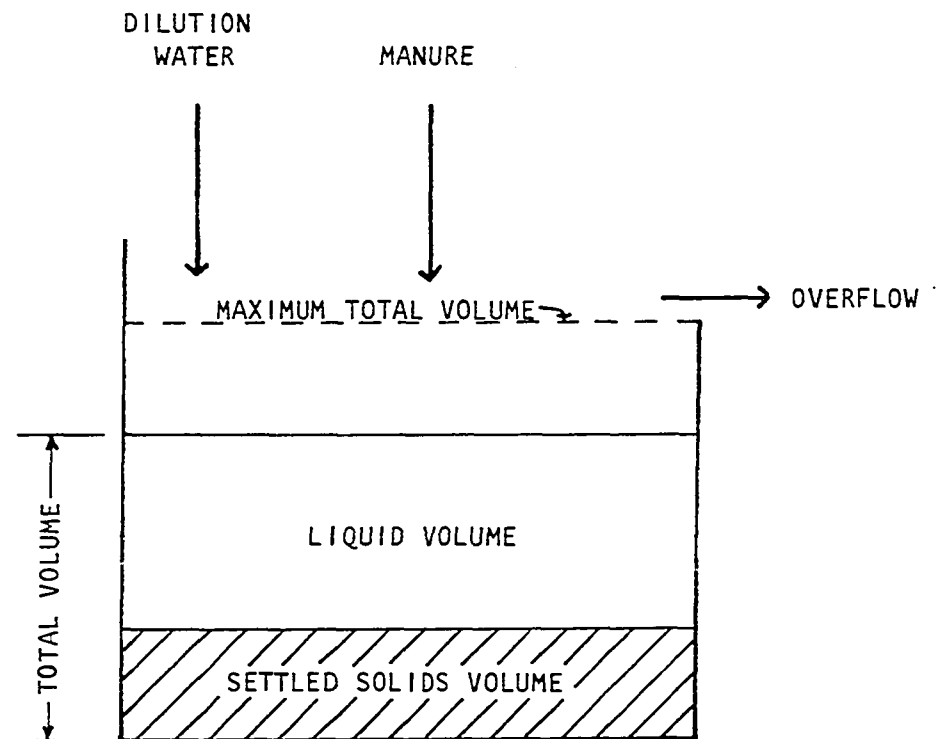


Figure 41. Diagram of the physical relationships of the factors considered in the solids concentration model

in the density of the manure after settlement has an effect on the solids-concentration increase in the flush water, but the percent settlement has the most predominant effect on solids increase in the flush water. Figure 42 shows the effect of the rate of solids settlement on the solids concentration of the flush water after 4 days. The values used in the model were close approximations of the flush system at Unit D. Shown on the figure is the final-solids concentration in the flush water predicted using the linear regression on the results. The 88% solids settlement indicated on Figure 42 is higher than the 74% poultry solids settlement shown in other research (Moore et al., 1975). However, solids-settlement percentages for flushed manure may be higher than laboratory tests because flushing systems tend to float manure into the storage area, thus maintaining larger agglomerates which settle faster than the fine agglomerates used in the laboratory.

Figure 42 also shows the concentration of solids in the flush water after 10 days. Using the solids settlement percentage indicated by the results, a projected solids concentration on the flush water of 9.2 g/l (.92%) is indicated. Figure 43 shows the increase in solids concentration in the flush water predicted over a long time period. The predicted line curves upward quickly after 30 days with an overflow because the storage area is almost full of settled solids. Settled solids filled the storage area during day 34 in the model with overflow. Assuming an infinitely large storage area, no overflow, allows higher solids concentration to be obtained gradually in the flush water because all the liquid added by the

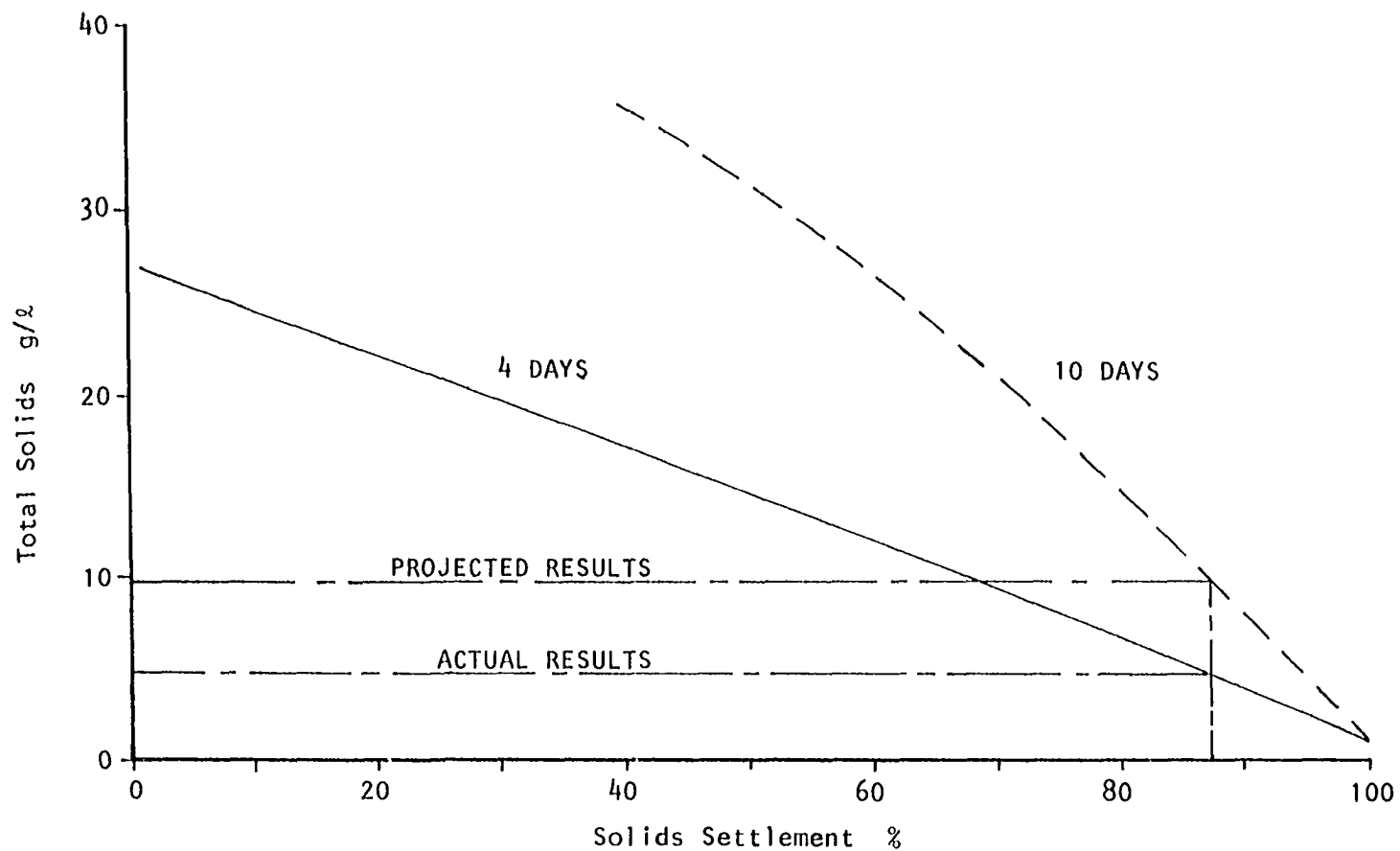


Figure 42. The relationship between total-solids concentrations in the flush water and the percent solids settlement predicted by the solids concentration model

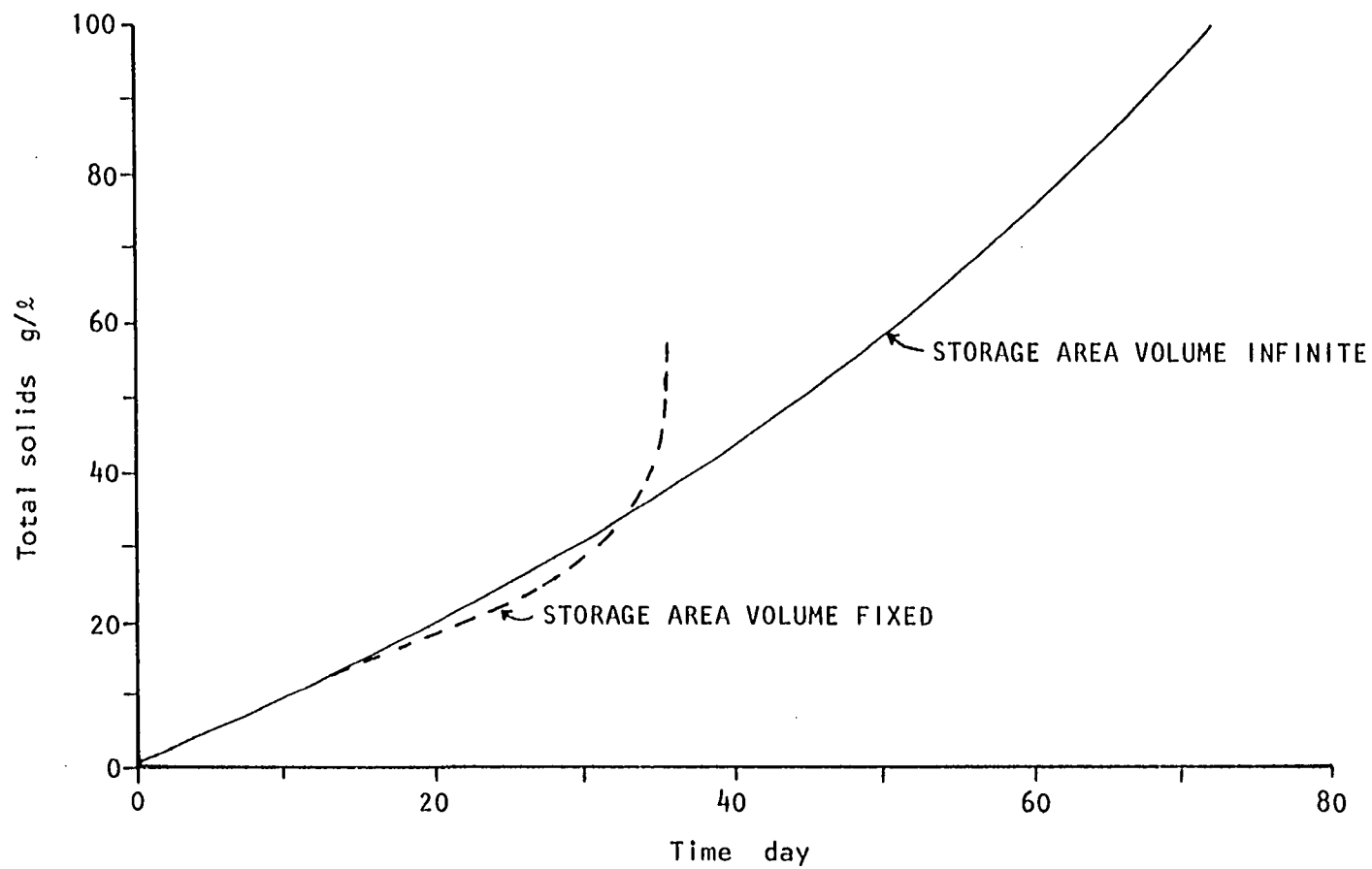


Figure 43. The relationship between total-solids concentrations in the flush water and time predicted by the solids concentration model

manure remains. Both lines shown on Figure 43 are conservative estimates of the solids concentrations because as the solids concentration in the flush water increases, the percent solids settlement will decrease, hindering settling.

While Figure 43 shows that the solids concentration in the flush water remains below 10 g/l (1%) for 10 days, the concentration of solids in the storage area is also increasing. The curves shown in Figure 44 indicate that after 10 days, the total-solids concentration in the storage area is approaching 60 g/l (6%). The maximum solids concentration in the storage area will be limited by the method of removing the manure and the method of final disposal.

While the model in Appendix B provides a method of estimating the performance of various in-house-recycling flushing systems, the basic question as to the interpretation of the results remains. Figure 43 shows the increase in solids concentration with time for the flushing system at Unit D; however, no definite answer is known for the concentration of solids that is unacceptable as flush water or the practical limit of the solids concentration that will prevent increases in pump-maintenance requirements. No investigations have been performed to determine the effect of the solids concentration in flush water on the cleaning ability of the flush water; although observation indicates that solids concentrations above 10 g/l (1%) in the flush water many result in unsatisfactory cleaning.

Assuming that recycling the flush water within a poultry building until the solids concentration in the flush water reaches 10 g/l may be acceptable for the flushing-system operation, there is still

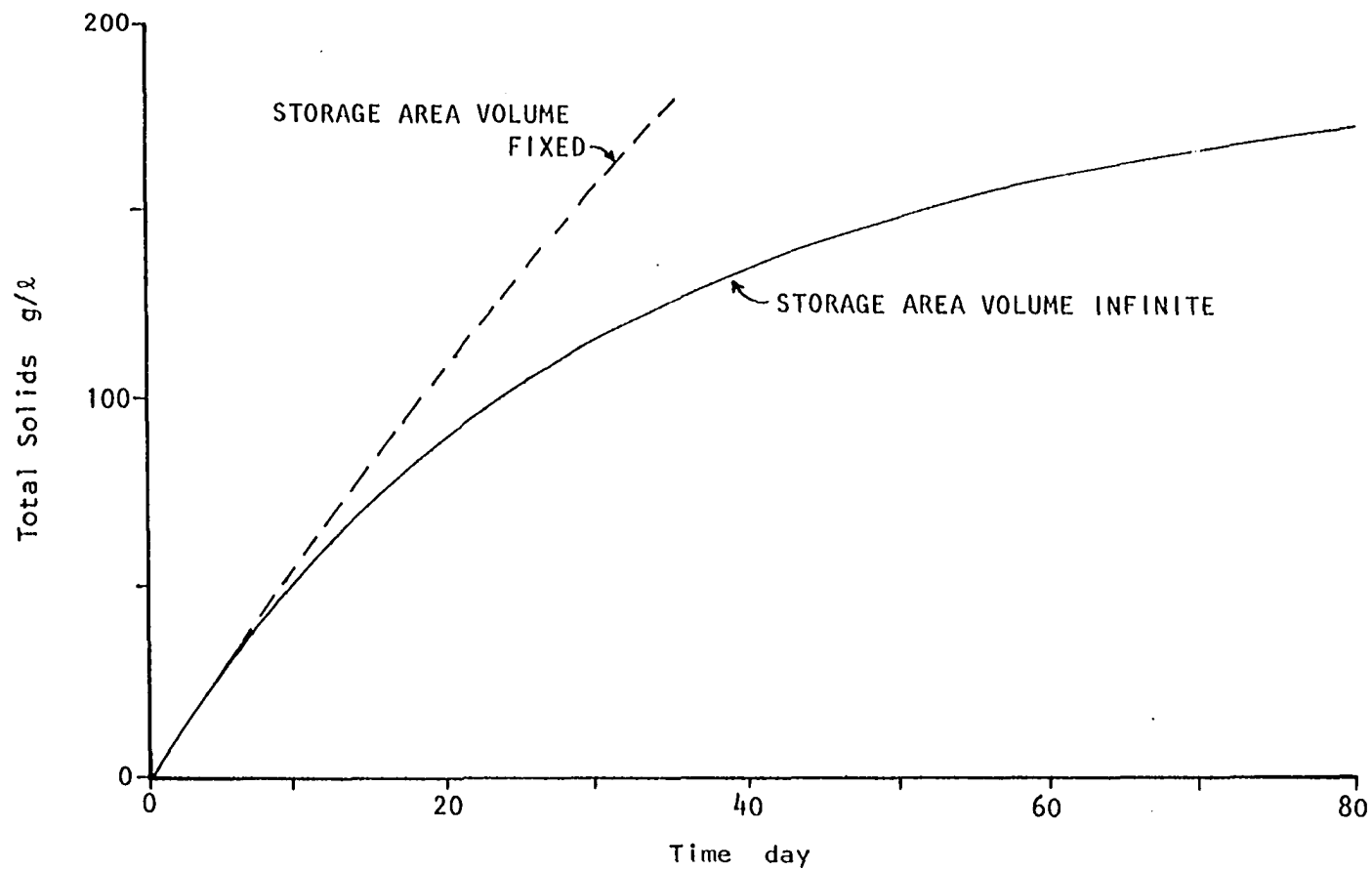


Figure 44. The relationship between total-solids concentrations in the storage area and time predicted by the solids concentration model

the consideration of ammonia-nitrogen concentration which will also be increasing. The relationship between total solids and the ammonia nitrogen in the flush water at Unit D is described in Equation 25.

$$\text{NH}_3 - \text{N} = 176 + 0.16 \text{ TS} \quad (25)$$

where

$\text{NH}_3 - \text{N}$ = ammonia-nitrogen concentration in the flush water mg/l

TS = total-solids concentration in the flush water mg/l

Equation 26 gives a reasonable estimation of the ammonia-nitrogen concentration of the flush water in a flush system using a settling area which can be used with the model in Appendix B. To keep atmospheric ammonia concentrations below 5 µg/l the results indicate that the ammonia-nitrogen concentration of the flush water must remain below 1327 mg/l. Equation 26 shows that to maintain an ammonia-nitrogen concentration below 1327 mg/l the total-solids concentration can not be allowed to exceed 7.2 g/l.

Economics

Annual variable costs for the flushing system at Unit D are listed as operating requirements in Table 24. Electricity and labor are the only variable costs listed because the system has not been in operation long enough to determine its maintenance requirements. The epoxy-coated metal trays and dosing siphons have required occasional cleaning, which is reflected in the labor requirement, but it has not been necessary to replace or repair either. The only equipment problems encountered have involved the recycle pump. Impellers have been wearing out rapidly as this problem was aggravated by an air leak on the pump's inlet pipe. It was not possible to

determine their normal operating life.

As included in Table 24, a projection of the operating requirements

Table 24. Operating requirements for flushing systems used in poultry housing

	Operating requirements /bird-yr
Unit D	1.7 kWh
.....	0.14 hr labor
Projected for commercial installation	0.9 kWh
.....	0.02 hr labor

for a flushing system in a commercial poultry-production unit is speculative. A reduced electrical demand probably results because of increase in bird density over the trays. On the other hand, the labor requirement for a flushing system is more closely related to the number of recycle pumps and flush tanks in the system than the number of birds.

The initial investment for a poultry unit should be about the same for either a flushing manure-handling system or a conventional manure-handling system. The added expense of the flushing trays is offset in part by the decreased floor area required with a flushing manure-handling system (Table 25). Manure-handling systems for the tri-load and four-deck systems shown in Table 25 require mechanical scrapers under the cages for cleaning which add to the initial and operating costs of these units.

The cage arrangement shown in Figure 45 is being used with a flushing manure-handling system. This cage arrangement allows for

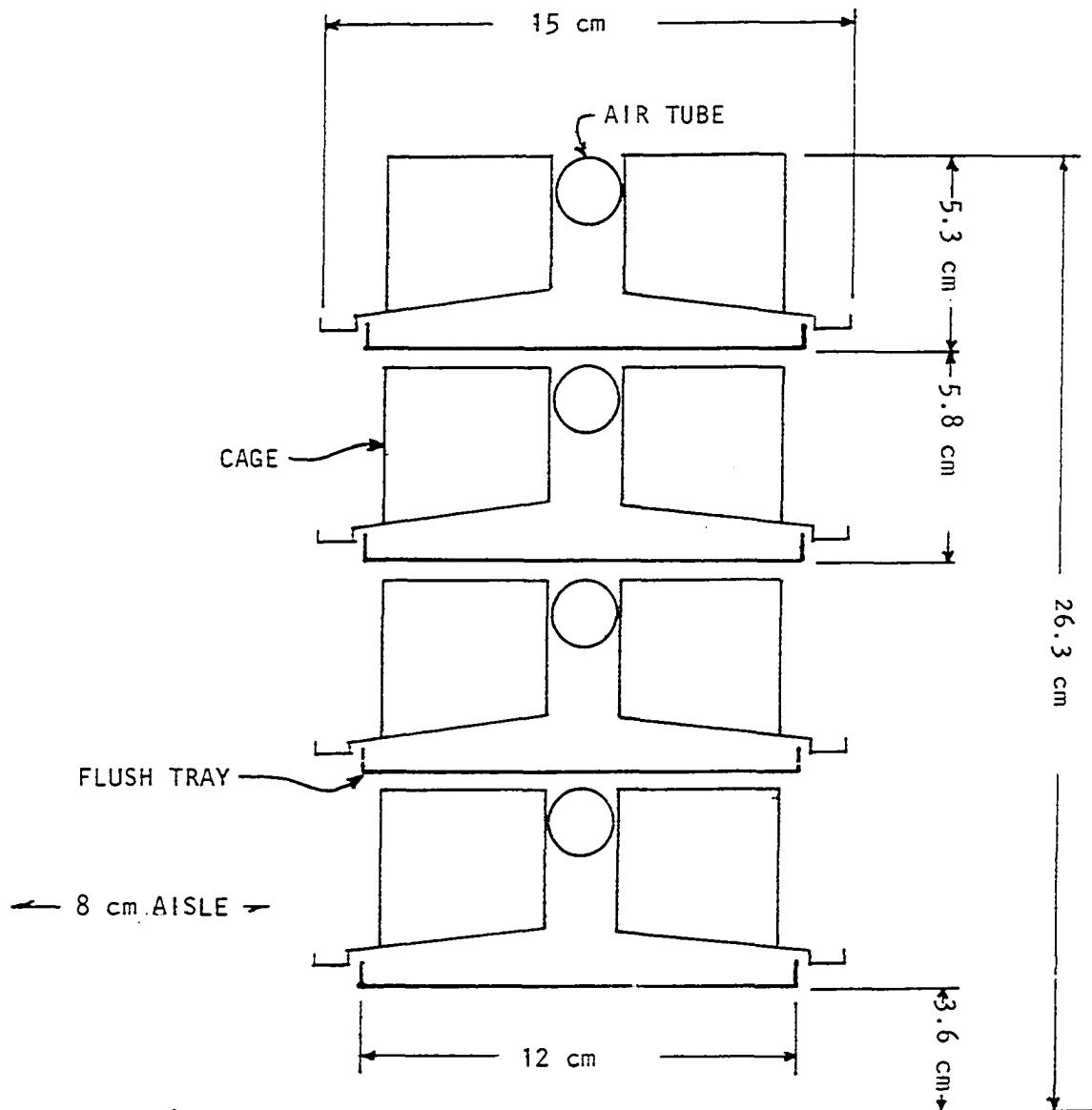


Figure 45. Cage arrangement recommended for use with a flushing-gutter manure handling system

Table 25. Floor area requirements for various manure-handling systems

	Floor area (cm ² /bird)	Building Width (m)	Ceiling height (m)
Stairstep			
Company A	613	12.8	2.3
Tri-high			
Company A	372	11.6	2.4
Company B	409	12.8	2.7
Four-deck			
Company B	344	14.3	3.1
Projected flush system			
Three-high	307	9.8	2.3
Four-high	232	9.8	2.9

an air tube installed between cages to provide ventilation to each cage. Air distribution in a poultry house using air tubes would be superior to the common-slot-inlet systems because each cage would have a source of outside air. A good air-distribution system will prevent areas in the house from becoming excessively hot or cold. Installation of an air-tube system may increase the initial cost of a poultry unit but this type of air-distribution system would have the advantage of providing a more uniformly productive environment for the birds. The cage arrangement and air distribution system described above was developed by Dr. Thamon Hazen, Iowa State University, Ames, Iowa, and Dr. Lynn Blaylock, Supersweet Research Farm, Courtland, Minnesota.

SUMMARY AND CONCLUSIONS

Overall, the system of manure management described in this dissertation functioned well, although minor mechanical failures occurred sporadically. A flushing system can provide an atmospheric environment that is compatible with a highly productive layer operation. Some specific conclusions that may be derived from the research results are:

1. At low concentrations of ammonia nitrogen in the flush water, atmospheric ammonia is absorbed by the flush water, thereby reducing atmospheric-ammonia concentrations in the building.
2. Excessive aeration of the flush water during passage through the building should be avoided because the resulting high pH levels inhibit ammonia absorption.
3. The flush trays provide the main area for ammonia exchange between the flush water and the atmosphere, because of the air velocity over the water during flushing.
4. In this study, the flush-water temperature was directly related to the building-air temperature. If the flush water were stored outside the building, e.g., in a lagoon, then the air temperature in the building might be affected by the flush water.
5. Atmospheric-ammonia concentrations remained low throughout the test ($< 3 \mu\text{g}/\text{l}$), indicating that a productive environment was being provided.
6. Ammonia-nitrogen concentrations in the lagoon water increased during the winter, which reduced the ammonia-absorption capacity of the flush water.

7. The atmospheric-ammonia concentration was directly proportional to the concentration of the ammonia-nitrogen in the flush water.
8. With the overflow from the drinking troughs entering the flush water, most water-quality concentrations remained constant; while without overflow, they increased linearly with time. The pH values did not follow this pattern but equilibrated to 7.3 with overflow and to 8.0 without.
9. Conductivity was highly correlated with most other water-quality measurements, except pH. This finding may be of considerable use as a management technique because conductivity measurements are easy to perform and the equipment is relatively inexpensive. The good correlations may be because the flush water was held in the building insufficiently long to undergo much biological decomposition.
10. Approximately 88% of the solids flushed from the trays settled in the recycled water-storage area.
11. The solids concentrations in the flush water that were experienced during this test (i.e., $TS < 0.5\%$) did not noticeably affect the manure removal from the trays.
12. Flushing frequency has a greater effect on manure removal than the volume of each flush.
13. When meandering must be controlled by dividing a wide flush tray into a multiplicity of narrow channels, the divider between two channels should be lower than the initial depth of flow to ensure that manure does not perch on the divider.
14. The flushing approach to manure handling in caged-layer houses

has low operating power requirements, low labor needs, and the capital investment in equipment is low.

15. At present, flushing systems are only feasible if the manure can be treated biologically in a lagoon or sequence of lagoons. Taken as an integrated system (flush equipment, lagoons, and land application), the investment in flush cleaning may not exceed the investment in competitive "dry" handling systems.
16. Flush systems offer the potential of greatly increased stocking density because units can be stacked vertically. Such increased stocking may require improved air-distribution systems.
17. Flush tanks for poultry should be designed with the discharge at the upper end of the trap so that the trap-charging hole can be eliminated. Small feathers seem to be very troublesome.

RECOMMENDATIONS FOR FUTURE STUDY

This work has shown the merit of flushing systems for poultry buildings. However, further research is required to provide the information necessary to optimize the design and operation of flushing systems for poultry. Based on the results of this work the following research should be conducted on flushing systems to encourage their use in poultry buildings.

1. The determination of the effect of solids concentration in the flush water, flushing frequency, flushing duration, tray slope, tray length, and tray geometry on manure removal from the trays.
2. Methods of improving flush water quality, i.e. reduction of ammonia-nitrogen and total-solids concentrations, to allow extended in-house recycling times.
3. Methods of flush water storage and treatment to alleviate the need of a lagoon.
4. Evaluation of the effect of flush water temperature on the air temperature of a poultry house.
5. Design of flush trays and supports to reduce their cost.
6. The effect on bird performance of a reduced ventilation rate in a poultry building utilizing a flushing system and an improved air distribution system, i.e. air tubes.
7. Determination of the reliability of atmospheric ammonia measurements as an indicator of a productive environment for poultry by determining the effect of low concentrations of

ammonia on bird performance,

8. Measuring the energy requirements, ventilation and waste handling, for total environmental control of a poultry building utilizing flushing.

To make the results of the aforementioned research more acceptable to commercial operators the research should be conducted in poultry buildings with a large bird population, >5,000 birds, and a high bird density (Table 25, Figure 45).

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APPENDIX A: RAW DATA

Table A1. Raw data

Trt	Hr	NH ₃ ^a μg/ℓ	Pt °C	TKN mg/ℓ	NH ₃ -N mg/ℓ	COD mg/ℓ	TS mg/ℓ	VS mg/ℓ	pH	Con mhos	TI °C	TO °C	RHI %	RHO %	VENT m ³ /min
1	0			39	20	281	1100	422							
1	2	1.20	13			405	1500	438			16	7	68	89	125
1	25	1.11	13			1258	2400	902			16	10	75	87	125
1	54	1.80	13				3200	1331			16	7	70	56	77
1	72						3700	1631							
1	0			45	23	452	1100	427							
1	5	2.15	11	80	63	308	1400	367			16	-3	68	96	77
1	17	2.66	12	256	192	1155	2200	700			16	-9	75	96	77
1	42	2.33	13	452	301		2900	1038			16	-7	73	96	77
1	60	3.02	13	562	398		3500	1372			14	-5	74	86	77
1	0			118	106	754	1600	506	7.15	2.10	14		76		
1	5	1.24	8	213	148	1123	2000	812	7.50	2.40	17	3	64	88	28
1	26	1.48	12	280	272	1871	2400	1104	7.85	3.20		-4		56	28
1	52	1.87	12	524	404	2832			7.90	4.30	14	-6	82	90	28
1	76	2.63	11	630	468	3974				4.90	15	-1	72	67	28
1	94	2.75	12	745	579	4509			7.85	5.60	14	-2	77	72	28
1	0		2	98	103	718	1500	456	7.20	1.95					
1	4	1.94	8	248	196	1529	2200	913	7.58	2.60	16	9	66	50	28
1	28	1.57	12	351	283	1739			7.98	3.35	14	5	77	84	28
1	52	2.31	12		391	2181	3200	1485	8.00	4.35	15	4	77	90	28
1	78	3.80	12	669	502	3009	4000	1948	8.00	5.15	14	2	77	82	28
1	94	3.12	10	728	576	3904	4700	2331	8.05	5.85	14	2	72	90	28
1	0		11	48	66	603	1100	494	7.68	1.50	21	21	60	49	
1	7	2.05	15			1012			8.00	2.00	21	21	60	49	125
1	24		13			1668	1900	840	7.60	2.90	19	19	62	58	125
1	48	1.10	14			2855	2900	1476	7.70	4.40	19	18	67	62	125
1	72	2.05	14			4956	4100	2165	7.90	5.90	21	22	55	38	125
1	95	2.99	14								17	16	70	68	28
1	0		11	61	61	324	1100	380	7.60	1.50					
1	5	2.44	18	175	138	902	1500	684	7.95	2.30	27	32	50	32	175
1	24	0.93	19	329	245	1616	2000	864	7.87	3.50	24	27	70	60	175

1	48	1.59	18	500	404	2687			7.86	4.75	23	23	77	73	175
1	78	1.84	21	708	497	4104	4200	2331	7.80	6.40	28	29	69	66	175
1	95	2.89	20	825	705	5019			7.90	7.20	24	28	70	51	175
2	0			79	67	460	1200	433							
2	7	1.28	12	65	34	333	1400	339			16	-6	72	94	28
2	30	1.33	13	74	39	402	1600	360			17	-3	78	86	28
2	55	1.14	13								16	-1	78	94	28
2	78	0.90	13	78	44	470	1600	451			16	1	78	94	28
2	0			102	99	542	1500	444							
2	7			74	52	326	1600	387							
2	33			77	54	433	1600	347							
2	8			55	47	307	1500	365							
2	31			55	47	365	1600	352							
2	56			55	55	312	1600	318							
2	80			57	61	510	1700	439							
2	0			118	130	762	1700	649							
2	22	0.82	12	76	39	244	1400	274			16	-2	64	80	28
2	44	1.09	12	52	36	330	1500	299			16	-7	63	52	28
2	73	0.93	12	71	53	376	1600	398			16	-6	72	57	28
2	0			125	136	733	1700	649	7.20	2.09					
2	6		11	107	66	429	1600	486	7.90	1.83	16	9	72	80	28
2	22		12	65	64	263	1600	302	7.60	1.56	16	5	72	91	28
2	51		12	40	35	276			7.40	1.67	17	13	64	72	28
2	74		12	60	41	295	1600	339	7.30	1.65	16	8	73	84	28
2	95		12	63	40	293	1600	370	7.30	1.64	16	2	68	90	28
2	0			123	128	781	1600	722	7.30	1.64					
2	6		12	65	43	324	1600	285	7.85	1.68	16	-1	68	89	28
2	26		11	53	31	279	1600	288	7.50	1.56	14	-8	77	72	28

APPENDIX B: SOLIDS CONCENTRATION MODEL

THE FOLLOWING PARAMETERS REMAIN CONSTANT

$$AN = 950.$$

AN = THE NUMBER OF ANIMALS

$$AVWT = 1587.$$

AVWT = THE AVERAGE WEIGHT OF THE ANIMALS (WT)

$$AVMP = 0.01325$$

AVMP = THE AVERAGE WEIGHT OF MANURE PRODUCED PER WEIGHT OF ANIMAL PER TIME UNIT (WT MANURE/WT ANIMAL/TIME)

$$DENM = 1125.$$

DENM = THE DENSITY OF THE MANURE PRODUCED (WT/VOL)

$$PS = 25.3$$

PS = THE PERCENT SOLIDS IN THE MANURE PRODUCED (%)

$$SPS = 16.5$$

SPS = THE PERCENT SOLIDS IN THE SETTLED SOLIDS (%)

$$DENSS = 1080.$$

DENSS = THE DENSITY OF THE SETTLED SOLIDS (WT/VOL)

$$VLADD = 0.0$$

VLADD = THE VOLUME OF DILUTION WATER ADDED PER UNIT TIME (VOL/TIME)

$$SCDW = .8$$

SCDW = THE SOLIDS CONCENTRATION OF THE DILUTION WATER (WT/VOL)

$$SAMV = 3400.$$

SAMV = THE STORAGE AREA'S MAXIMUM VOLUME (VOL)

THE WEIGHT OF THE MANURE PRODUCED PER UNIT TIME IS -

$$WMP = AN \cdot AVWT \cdot AVMP$$

WMP = THE WEIGHT OF THE MANURE PRODUCED PER UNIT TIME (WT/TIME)

THE VOLUME OF MANURE PRODUCED PER UNIT TIME IS -

$$VMP = WMP/DENM$$

VMP = THE VOLUME OF THE MANURE PRODUCED PER TIME UNIT (VOL/TIME)

$$PSS = -10.$$

PSS = THE PERCENT OF THE SOLIDS PRODUCED WHICH SETTLE IN THE STORAGE AREA (%)

$$DO\ 100\ I = 1,11$$

$$PSS = PSS+10.$$

THE FOLLOWING PARAMETERS VARY WITH THE PERCENT SOLIDS SETTLEMENT

$$WSS = WMP*PS*PSS/10000.$$

WSS = THE WEIGHT OF THE SETTLED SOLIDS PER TIME UNIT (WT/TIME)

THE WEIGHT OF DISSOLVED AND SUSPENDED SOLIDS PER UNIT TIME IS -

$$WDSS = WMP*PS*(100.-PSS)/10000.$$

WDSS = THE WEIGHT OF THE DISSOLVED AND SUSPENDED SOLIDS PER TIME UNIT (WT/TIME)

$$DAY = 0.$$

THE FOLLOWING PARAMETERS MUST BE RESET WHEN DAY = 0.

$$TVSAI = 3000.$$

TVSAI = THE TOTAL VOLUME IN THE STORAGE AREA AT THE BEGINNING OF EACH TIME UNIT (VOL)

$$TWSSI = 0.$$

TWSSI = THE TOTAL WEIGHT OF SETTLED SOLIDS IN THE STORAGE AREA AT THE BEGINNING OF EACH TIME UNIT (WT)

$$CDSS = 1.38$$

CDSS = THE CONCENTRATION OF DISSOLVED AND SUSPENDED SOLIDS IN THE LIQUID VOLUME ABOVE THE SETTLED SOLIDS IN THE STORAGE AREA (WT/VOL)

$$DO\ 200\ J = 1,16$$

$$DAY = DAY+0.25$$

THE FOLLOWING PARAMETERS VARY WITH TIME

THE TOTAL VOLUME IN THE STORAGE AREA AFTER ONE TIME UNIT IS -

$$TVSA = TVSAI + VMP + VLADD$$

TVSA = THE TOTAL VOLUME IN THE STORAGE AREA AT THE END OF EACH TIME UNIT (VOL)

THE AMOUNT OF OVERFLOW FROM THE STORAGE AREA IS -

$$FVER = TVSA - SAMV$$

FVER = THE OVERFLOW VOLUME (VOL)

THE TOTAL VOLUME IN THE STORAGE CANNOT BE GREATER THAN THE MAXIMUM VOLUME OF THE STORAGE AREA

IF (FVER.GT.0.) GO TO 10

GO TO 20

10 TVSA = SAMV

20 CONTINUE

THE TOTAL SETTLED SOLIDS AFTER ONE TIME UNIT IS -

$$TWSS = TWSSI + WSS$$

TWSS = THE TOTAL WEIGHT OF SETTLED SOLIDS IN THE STORAGE AREA AT THE END OF EACH TIME UNIT (WT)

THE VOLUME OF THE TOTAL SETTLED SOLIDS AFTER ONE TIME UNIT IS -

$$VTWSS = TWSS / ((SPS/100.) * DENSS)$$

VTWSS = THE VOLUME OF THE SETTLED SOLIDS IN THE STORAGE AREA (VOL)

THE LIQUID VOLUME REMAINING IN THE STORAGE AREA ABOVE THE SETTLED SOLIDS IS -

$$LV = TVSA - VTWSS$$

LV = THE VOLUME OF LIQUID ABOVE THE SETTLED SOLIDS IN THE STORAGE AREA (VOL)

THE DISSOLVED AND SUSPENDED SOLIDS ADDED BY THE DILUTION WATER IS -

$$SADW = VLADD * SCDW$$

SADW = THE WEIGHT OF SOLIDS ADDED BY THE DILUTION WATER (WT/TIME)

THE WEIGHT OF THE SOLIDS LEAVING WITH THE OVERFLOW IS -

IF (FVER.GT.0.) GO TO 30

WSL = 0.0

WSL = THE WEIGHT OF DISSOLVED AND SUSPENDED SOLIDS LEAVING
WITH THE OVERFLOW WATER (WT)

GO TO 40

30 WSL = FVER*CDSS

THE WEIGHT THE DISSOLVED AND SUSPENDED SOLIDS IN THE LIQUID ABOVE THE
SETTLED SOLIDS AFTER ONE TIME UNIT IS -

40 WDSR = LV*CDSS+SADW+WDSS-WSL

WDSR = THE WEIGHT OF DISSOLVED AND SUSPENDED SOLIDS IN THE
VOLUME OF LIQUID ABOVE THE SETTLED SOLIDS AT THE END
OF EACH TIME UNIT (WT)

THE SOLIDS CONCENTRATION IN THE LIQUID VOLUME ABOVE THE SETTLED SOLIDS IS -

CDSS = WDSR/LV

THE SOLIDS CONCENTRATION OF ALL THE SOLIDS IN THE STORAGE AREA IS -

TSC = (WDSR+TWSS)/TVSA

TSC = THE CONCENTRATION OF ALL THE SOLIDS IN THE STORAGE AREA
(WT/VOL)

RESET INITIAL VALUES TO THOSE CALCULATED AFTER ONE TIME UNIT -

TVSAI = TVSA

TWSSI = TWSS

200 CONTINUE

PRINT, PSS, DAY, CDSS, TSC, TVSA, FVER

100 CONTINUE

STOP

END

Table B1. Computer output from the solids concentration model

<u>PSS</u> <u>%</u>	<u>DAY</u>	<u>CDSS</u> <u>g/l</u>	<u>TSC</u> <u>g/l</u>	<u>TVSA</u> <u>l</u>	<u>FVER</u> <u>l</u>
0.	4.	27.1	27.1	3284.	-116. ^a
10.	4.	24.7	26.8	3284.	-116.
20.	4.	22.2	26.5	3284.	-116.
30.	4.	19.8	26.3	3284.	-116.
40.	4.	17.3	26.2	3284.	-116.
50.	4.	14.7	26.0	3284.	-116.
60.	4.	12.1	25.9	3284.	-116.
70.	4.	9.5	25.8	3284.	-116.
80.	4.	6.8	25.8	3284.	-116.
90.	4.	4.1	25.8	3284.	-116.
100.	4.	1.4	25.8	3284.	-116.

^aNegative values indicate zero overflow.